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14. ABSTRACT

The purpose of this research study was to investigate the relationship between blast-induced traumatic brain injury (TBI), specifically the auditory (i.e., hearing) and vestibular (i.e., balance) symptoms of military Warfighters who were recently deployed in support of Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF). The study employed a prospective, between-subjects research design comparing an experimental group (service members who have been diagnosed with BI-TBI) to a control group (service members who do not have clinical symptoms consistent with BI-TBI). A total of 96 volunteers were recruited and consented, with a final enrollment of 68 participants. Results show that there are differences between the vestibular function of service members without history of BI-TBI and those with a history of BI-TBI that could be diagnosed clinically with instrumentation that proved to be reliable and well tolerated by service members with TBI.

15. SUBJECT TERMS
None provided.

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INTRODUCTION

Purpose and Scope of Research: TBI has been described in the media as the signature injury of the current conflicts in Iraq and Afghanistan. Soldiers suffer TBI as the result of blast from improvised explosive devices (IED), mortars, rocket-propelled grenades (RPG) and from impacts to the head from accidents caused by enemy action, equipment failure, or other factors. The specific pathologies resulting from TBI can be many; however, the impacts on balance and auditory functions are among the most frequent and debilitating injuries seen in patients with TBI (Maskell, 2006; Sherer, 2006).

The purpose of this study is to evaluate and characterize the vestibular, auditory, and oculomotor sequelae to blast exposure in Warfighters diagnosed with blast-induced traumatic brain injury (BI-TBI). The results of this study are intended to contribute to the development of objective diagnostic measures appropriate for the BI-TBI population, and to the development of empirical vestibular, auditory, and oculomotor return-to-duty standards. It is believed that the range of sensory findings measured in a sample of BI-TBI patients will provide an observational basis for measuring treatment progression, as well as empirical methods for establishing the severity of the sensory loss due to blast exposure.

Methods

Participants: A total of 96 volunteers were recruited and consented, with a final enrollment of 77 participants.

Table 1. Number of participants.

	Consented	Screened	Enrolled
Non-TBI group	29	29	26
BI-TBI group	67	67	51
Totals	96	96	77

For inclusion in the BI-TBI group, subjects met the below criteria:

- Males or females from 19-55 years of age and of all races
- Diagnosed with BI-TBI from injuries sustained in a combat zone

Exclusion criteria from either group included the following criteria:

- Brain injury resulting from a penetrating wound to the head, neck, face or brain (to include gunshot wounds)
- Presence of severe aphasia
- A patient involved in a previous military or sports event with a history of traumatic brain injury incurred outside OIF\OEF
- History of neuropsychiatric disorders antedating the head injury (e.g. hypochondriasis, major depression, schizophrenia)
- Pregnancy
- History of participation in organized boxing or "tough man" competitions
- Prior disorders of hearing and balance including**:**
    - Meniere's disease
    - Chronic migraine
    - Multiple sclerosis
    - Vestibular neuritis
    - Vestibular schwannoma
    - Sudden sensorineural hearing loss
    - Cerebrovascular disorders
    - Whiplash injury
    - Systemic disorders: e.g. chronic renal failure, cirrhosis of the liver, etc.
    - Medications and drugs which depress the sensorium precluding patient compliance with the testing (considered on a case-by-case basis)
    - Previous contraindicating surgeries at the discretion of the study physicians or audiologists

Experimental Design: The study employed a prospective, between-subjects research design comparing an experimental group (Soldiers who have been diagnosed with BI-TBI) to a control group (Soldiers who do not have clinical symptoms consistent with BI-TBI).

Study hypotheses were as follows:

The study group diagnosed with blast-induced traumatic brain injury (BI-TBI) will exhibit more auditory and vestibular abnormalities than the control group in the following ways:

1) Off-set rotational chair testing will yield more asymmetries, abnormal velocities and gain results. The Saccade, Smooth Pursuit, OKN, and Unilateral Centrifugation subtests will yield asymmetries in velocities and gain post blast exposure.

2) Tympanometry test results (a measure of the integrity of the outer and middle ear systems) will yield more flaccid eardrum mobility (Type Ad), consistent with total or partial disarticulation of the ossicular chain.

3) Tympanometry will yield more results consistent with perforated tympanic membranes (Type B with large external auditory canal volume).

4) Pure tone audiometric test results will indicate more hearing loss (conductive, sensorineural or mixed).

5) Subjective measures recorded on the Dizziness Handicap Inventory (DHI), Department of Veteran's Brain Injury Center (DVBIC) Questionnaire, and Blast Exposure Survey (and other medical case history information revealed during the informal intake/consent process) will capture more complaints of auditory and vestibular symptoms.

6). Visual deficits that rely on central processing, but not peripheral processing, will have strong correlations with executive attentional mechanisms.

Apparatus: The Neuro-Kinetics I-Portal Neuro-Otologic Test Center (NOTC) System was used to collect the vestibular and oculomotor data. Standard FDA approved clinical audiometers and immittance units calibrated to ANSI standards were used to collect the hearing acuity and middle ear test data, respectively. Questionnaires and screening tools were utilized to collect information about volunteer participants' auditory and vestibular symptoms, blast exposure, and to further qualify the presence or absence of a BI-TBI

BODY

Dependent variables

The dependent measures collected in this study included the results of a battery of questionnaires and screening tools, audiometric and vestibular tests. A brief description of each dependent measure and a summary of statistical analysis follow.

Subjective screening measures qualified the type and severity of a patient's BI-TBI, auditory and vestibular symptoms, and blast exposure. After the volunteer was assessed by a physician and consented to participate in the study, the following questionnaires and screening tools were administered:

Questionnaires

Dizziness Handicap Inventory (DHI)

This validated questionnaire was develop clinically and is commonly used by clinicians to qualify and quantify symptoms associated with dizziness, light-headedness, vertigo, migraine

associated dizziness, and to assist with identifying complaints of dizziness related to anxiety, depression, post-traumatic-stress disorder, etc. This tool captured subjective symptoms associated with BI-TBI prior to completing the objective measures. This instrument is located in Appendix A of this document.

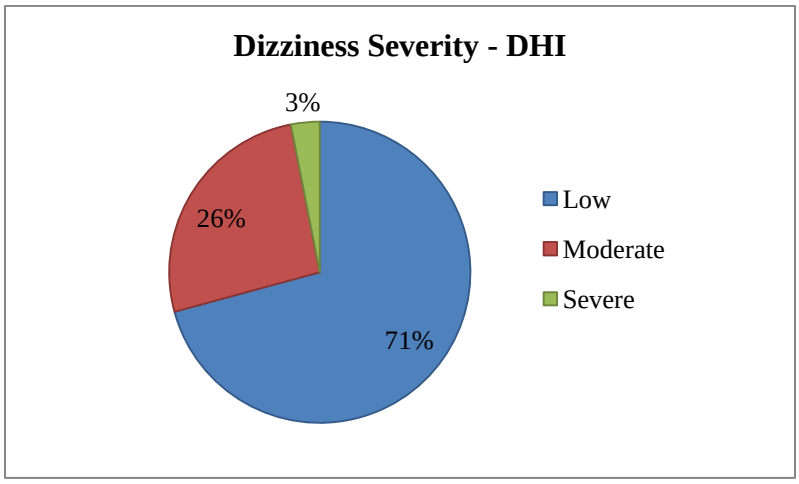

Figure 1. Dizziness Handicap Inventory ratings of dizziness for BI-TBI group.

Department of Veteran's Brain Injury Center (DVBIC) 3 Question Screening Tool

This is one of two validated screening tools for TBI recommended by the Institutes of Medicine. This measure was administered as a tool for qualifying the general symptoms associated with BI-TBI prior to completing the objective auditory and vestibular test battery. A copy of the DVBIC 3 Question Screening Tool is located in Appendix B.

Table 2. Department of Veteran's Brain Injury (DVBIC) 3 Question Screening Tool results.

	Injury Verified	Positive Screen	Symptoms Related to TBI
BI-TBI	67	64	67
Non-TBI	2	1	0

Blast Exposure Survey

The three-question blast screening tool was developed at the U.S. Army Aeromedical Research Laboratory specifically for this protocol. This screening tool is intended to assist in qualifying, not quantifying, a research participant's blast exposure. It is a means of allowing the research team to categorize the approximate distance and type of blast to which the participant was

exposed, and document the amount of time since the blast exposure. This instrument is located in Appendix C.

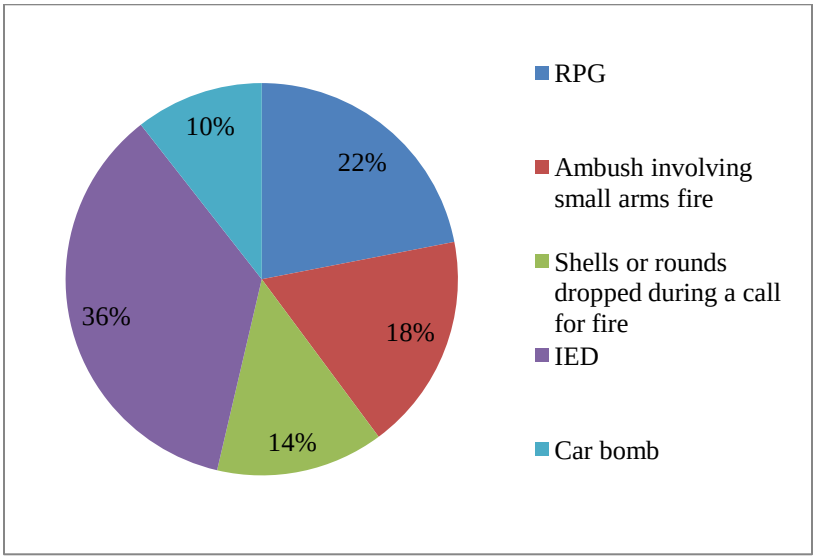

Figure 2. Blast Exposure Survey Question 1 (What type of blast were you exposed to?) for BI-TBI group only.

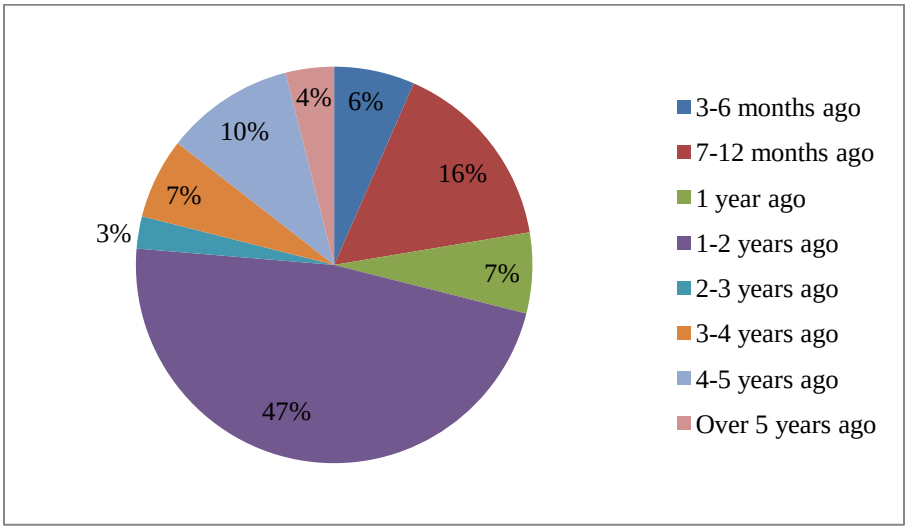

Figure 3. Blast Exposure Survey Question 1 (When were you exposed to the blast?) for BI-TBI group only.

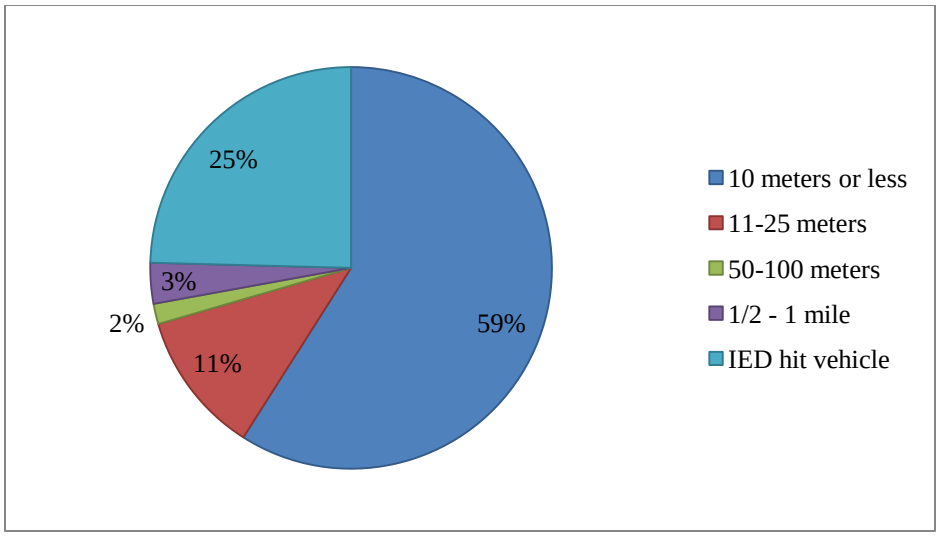

Figure 4. Blast Exposure Survey Question 1 (Approximately how far were you from the blast?) for BI-TBI group only.

Auditory Test Battery

The audiometric test battery included air and bone conducted pure-tone thresholds, a test of middle-ear function (tympanometry), and otoscopy to identify any abnormalities of the ear canal or tympanic membrane (eardrum). A more detailed description of these evaluations is below.

Otoscopy

A certified audiologist performed an otoscopic examination of the outer ears. This is a standard clinical evaluation which is performed by looking in the participant's ear canals with a lighted otoscope for the purpose of verifying that the tympanic membranes are visible and appear normal, and that the ear canals are free of debris and cerumen (ear wax). If cerumen or evidence of outer/middle ear pathology is present, the participant was referred for appropriate medical management before participation in the current study.

Tympanometry

A certified audiologist measured the mobility and integrity of the eardrum and middle ear system using a Grason-Stadler GSI TympStar Middle Ear Analyzer (a device commonly used in standard clinical practice). To perform this test, a small probe (rubber ear tip) was placed in the entrance of the external auditory meatus (ear canal) to completely seal the opening to the canal. A 226 Hertz (Hz) tone was introduced through this probe while a mild positive and negative pressure was applied. This test measures the flexibility of the tympanic membrane and can, for example, indicate the abnormal presence of fluid in the middle ear system consistent with an ear infection, severe cold, allergies or sinus problems.

There are 5 types of tympanograms: type A within normal limits, type As normal pressure with abnormally low compliance, type Ad normal pressure with abnormally large compliance, type B abnormal pressure and abnormal compliance, type C abnormal pressure normal compliance.

Testing disclosed Type Ad to be the most common abnormality in both groups but having a low occurrence in both groups.

Table 3: Number of tympanograms by type

	Type A	Type As	Type Ad	Type B	Type C
Non-TBI	51	0	5	0	3
TBI	115	0	10	1	0

Air and bone-conduction audiometry

A certified audiologist administered an audiometric evaluation. Air-conduction audiometric thresholds were measured and recorded for 0.125, 0.25, 0.5, 1.0, 2.0, 3.0, 4.0, 6.0 and 8.0 kHz (routine conventional audiometric thresholds) and were obtained at higher frequencies by recording at 9.0, 10.0, 11.2, 12.5, 14.0 and 16.0 kHz using circumaural headphones. Bone-conduction thresholds were measured at .5, 1.0, 2.0 and 4.0 kHz. Threshold is defined as the "lowest hearing level at which responses occur in at least one-half of a series of ascending trials, with a minimum of two responses out of three required at a single level." Testing was performed in a sound treated booth certified to limit background noise to acceptable clinical levels as specified by the American National Standards Institute. Analysis was conducted on the differences between groups for the following variables: *low frequency average right ear, low frequency average left ear, high frequency average right ear, and high frequency average left ear.*

A one way ANOVA (using alpha of .05) showed statistical significance for all of the tested outcomes.

Low frequency average right ear: F (1, 91) = 16.79, $p < .05$ with 15.6% of the variability in the outcome attributable to between-group differences The TBI group obtained a higher mean (M = 13.36, SD = 8.95) as opposed to the non-TBI group (M = 6.05, SD = 3.64).

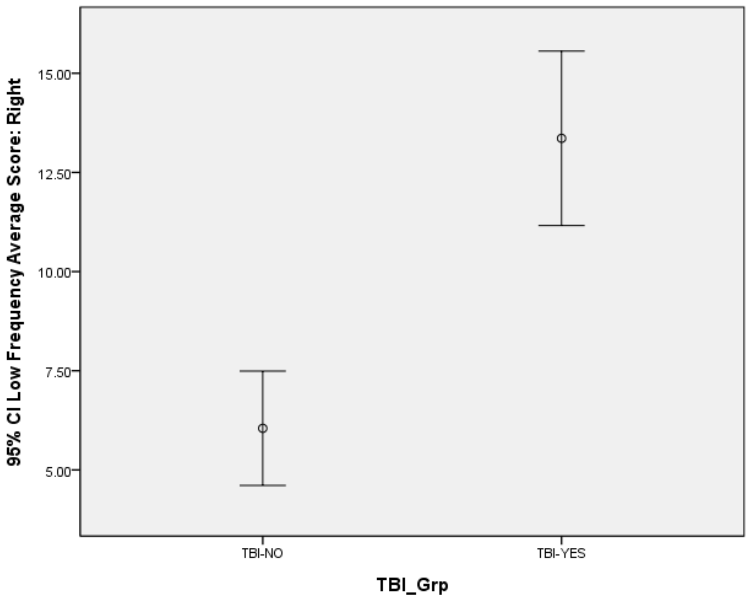

Figure 5. 95% Confidence Interval for the *low frequency average right ear variable* on the Auditory Test Battery.

Low frequency average left ear: F (1, 91) = 15.55, $p < .05$ ($\eta^2 = .146$, with 14.6% of the variability in the outcome attributable to between-group differences. The TBI group obtained a higher mean (*M* = 13.56, *SD* = 8.24) as opposed to the non-TBI group (*M* = 7.04, *SD* = 3.74).

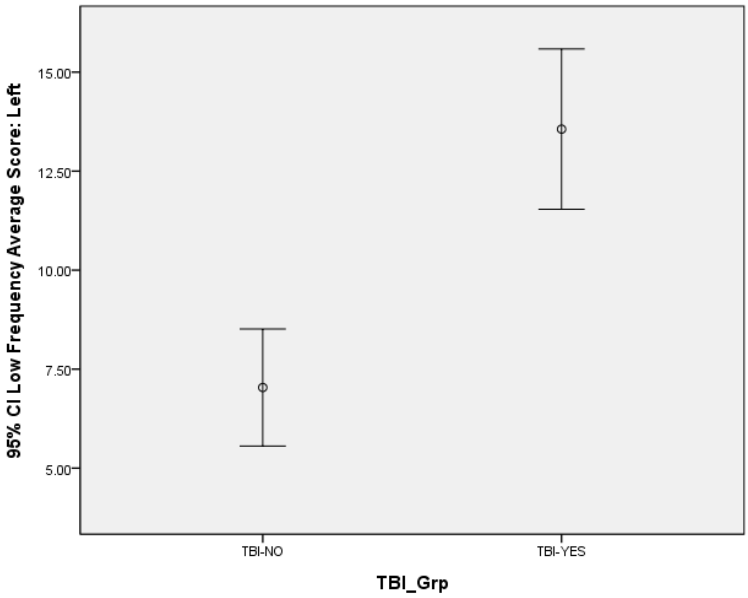

Figure 6. 95% Confidence Interval for the *low frequency average left ear* variable on the Auditory Test Battery.

High frequency average right ear: F (1, 91) = 18.62, $p < .05$ with17% of the variability in the outcome attributable to between-group differences. The TBI group obtained a higher mean (*M* = 16.28, *SD* = 12.89) as opposed to the non-TBI group (*M* = 5.31, *SD* = 4.21).

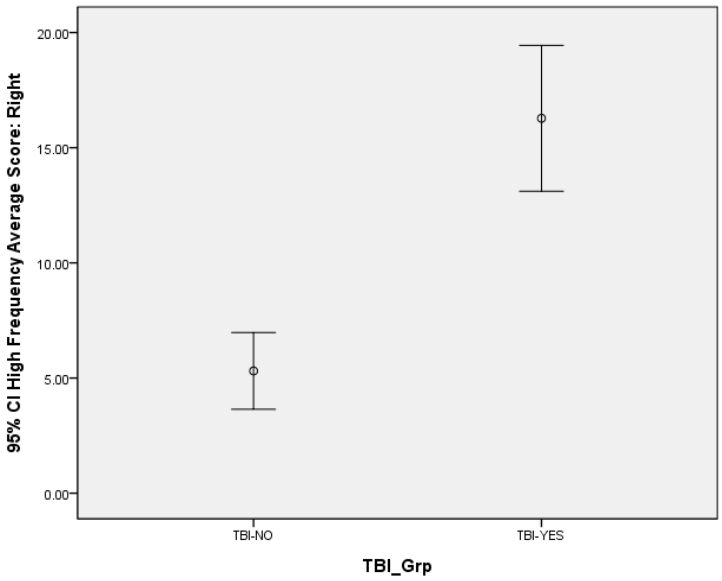

Figure 7. 95% Confidence Interval for the *high frequency average right ear* variable on the Auditory Test Battery.

High frequency average left ear: F (1, 91) = 14.07, $p < .05$ with13.4% of the variability in the outcome attributable to between-group differences). The TBI group obtained a higher mean (*M* = 17.22, *SD* = 13.09) as opposed to the non-TBI group (*M* = 7.35, *SD* = 6.07).

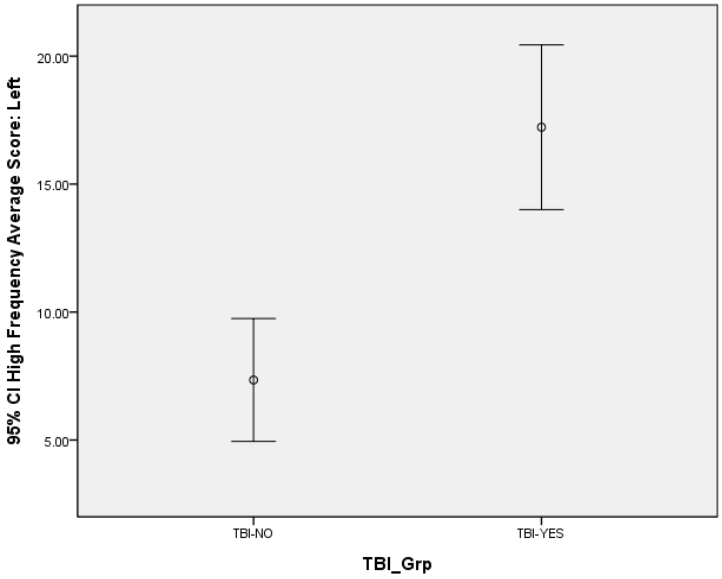

Figure 8. 95% Confidence Interval for the *high frequency average left ear* variable on the Auditory Test Battery.

Table 4. Mean air-conducted audiometric averages (in decibels) for non-TBI participants.

(Hz)	125	250	500	1k	2k	3k	4k	6k	8k	9k	10k	11.2k	12.5k	14k	16k
Right (dB)	16.9	14.8	12.9	11.6	13.3	18.2	25.2	27.2	26.6	30.5	25.0	24.5	24.0	18.3	20.9
Left (dB)	16.9	15.5	12.2	11.4	11.4	16.4	19.9	23.8	20.5	24.6	21.3	17.5	17.6	26.4	20.5

Table 5. Mean air-conducted audiometric averages (in decibels) for BI-TBI participants.

(Hz)	125	250	500	1k	2k	3k	4k	6k	8k	9k	10k	11.2k	12.5k	14k	16k
Right (dB)	19.0	19.0	20.7	10.6	11.5	14.6	18.2	22.5	20.2	25.5	22.2	21.2	23.3	24.0	23.6
Left (dB)	19.0	19.1	20.8	10.7	11.5	14.7	18.4	22.3	20.4	25.5	22.2	21.2	23.3	24.0	23.6

Vestibular Test Battery

The Neuro-Kinetics, Inc. I-Portal NOTC system includes an off-set rotary chair assembly, light tight enclosure, pursuit tracker oculomotor stimulus, optokinetic stimulus, and the I-Portal 100Hz VOG Goggle. Data from these procedures were collected by personnel trained to use the I-Portal system on the following comprehensive vestibular and visual (oculomotor) subtests (that are described below according to the general anatomy and physiological target area and examiner instructions for testing):

- Spontaneous Nystagmus
- Smooth Harmonic Acceleration (.01, .08, .32, .64, 1.75)
- Saccades Horizontal and Vertical
- Smooth Pursuit Horizontal (0.1, 0.2, 0.4, .71)
- Smooth Pursuit Vertical (0.1, 0.2, 0.4, .71)
- Gaze Horizontal
- Gaze Vertical
- OKN Trapezoidal (20, 40, 60)
- Visual Enhancement (.08, .16, .32, .64)
- Visual Suppression (.08, .16, .32, .64)
- Subjective Visual Vertical
- Subjective Visual Horizontal

A brief description and a summary of statistical analysis for each Neuro-Kinetics, Inc. I-Portal NOTC system subtest follows. A one-way analysis of variance (ANOVA) was conducted on data from each subtest and data were tested for significance at an alpha level of 0.05, chosen to determine whether any observed differences in the means were due to chance, or were due to changes in the experimental variables.

Spontaneous Nystagmus

Description: Nystagmus refers to the involuntary movement of the eyeball, part of the vestibulo-ocular reflex (VOR). This reflex, mediated in the brainstem, serves to keep an image stabilized on the retina as the head moves (such as occurs while walking). The reflex causes horizontal and vertical movements of the eyeball as well as rotational movements as the head tilts from side to side. Measurement of spontaneous nystagmus, involuntary eye movement in a darkened room, is important because the presence of spontaneous nystagmus will influence measures of slow phase symmetry.

The Spontaneous Nystagmus test started with a 3-second laser dot projection at its center position, remained stationary for 3 seconds, and turned off for 15 seconds, the sequence will repeat once, implementing two total cycles. The participant was instructed to keep his/her eyes on the dot, or on the location where the dot was during the testing period. This subtest resulted in four segments for analysis: *horizontal fixation lights on, horizontal fixation lights off, vertical fixation lights on, and vertical fixation lights off.*

Results: A one-way ANOVA was conducted on the Spontaneous Nystagmus subtest, using an alpha level of 0.5. There were no significant between-group differences on the number beats in any of the four outcomes for this subtest, and no effect size larger than η^2 of .019 (1.9% of the explained variance). Given the nature of the variable (a 'count' variable) it could be argued that a Poisson regression approach would be more appropriate. Thus between group differences for each segment were analyzed using the Poisson distribution with the log link function. The Poisson regression analysis showed significant differences between groups in the *horizontal fixation lights off, vertical fixation lights on,* and *vertical fixation lights off* number of nystagmus beats. In these three conditions, the BI-TBI group had a larger mean number of nystagmus beats.

Smooth Harmonic Acceleration (.01, .08, .32, .64, 1.75)

Description: In the Sinusoidal Harmonic Acceleration subtest, the rotary chair osculated in a sinusoidal motion (back and forth) with the vertical axis of the volunteer's head centered between the two vestibular systems. There were five rotational frequencies in this subtest: In the .01, .08, .32, .64, and 1.75 Hertz (Hz). In this subtest, there were three variables for analysis: *gain average, asymmetry, and phase*.

Smooth Harmonic Acceleration (.01) Results: One-way ANOVA using alpha of .05 showed no statistical significance for any of the outcomes. Though not significant, the largest effect size was found for *asymmetry*: F (1, 73) = 2.95, p = .09 (η^2 = .039, i.e., 3.9% of the variability in the outcome is attributable to between-group differences). The non-TBI group obtained a higher mean (M = 7.12, SD = 10.48) as opposed to the BI-TBI group mean (M = 2.90, SD = 9.97).

The Mann-Whitney non-parametric analogue to the two-group ANOVA was performed and as with the findings for the ANOVA, there were no significant between-group differences on the ranks for any of the variables.

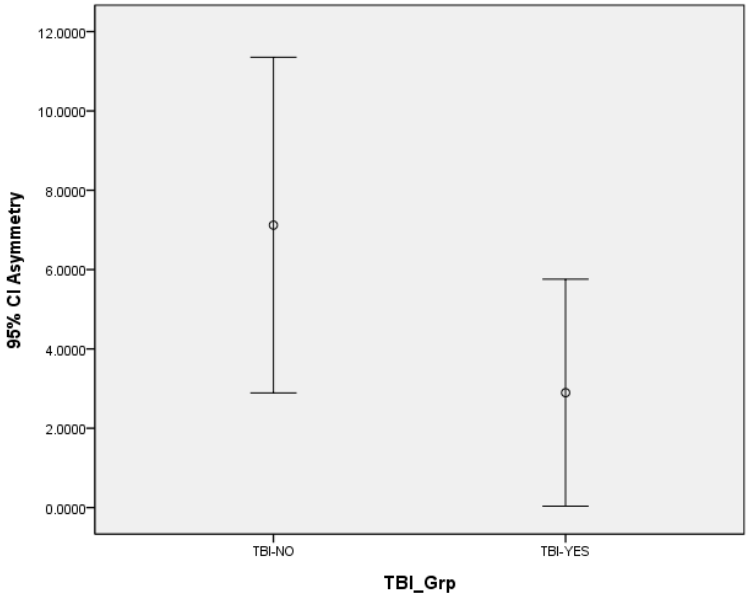

Figure 9. 95% Confidence Interval for the *asymmetry* variable on the Smooth Harmonic Acceleration (.01) subtest.

Smooth Harmonic Acceleration (.08) Results: No statistical significance was found for any of the variables on the Smooth Harmonics Acceleration (0.8) subtest. All of the effect sizes were very small with the largest obtained for *phase* (with the outlier) which was still a negligible .7% variance explained.

A Mann-Whitney test was performed and commensurate with the findings for the ANOVA, there were no significant between-group differences on the ranks for any of the variables.

Smooth Harmonic Acceleration (.32) Results: Significance was found for *asymmetry: F* (1, 73) = 7.18, *p* = .009 (η^2 = .09, i.e., 9% of the variability in the outcome is attributable to between-group differences) when conducting the one way ANOVA (using alpha of .05). The non-TBI group

obtained a higher mean (*M* = 8.78, *SD* = 11.70) as opposed to the TBI group mean (*M* = 1.90, *SD* = 9.96).

A Mann-Whitney Given non-parametric analogue to the two-group ANOVA was performed and commensurate with the findings for the ANOVA, there were significant between-group differences on the ranks for *asymmetry*: *Z* = -2.85, *p* = .004.

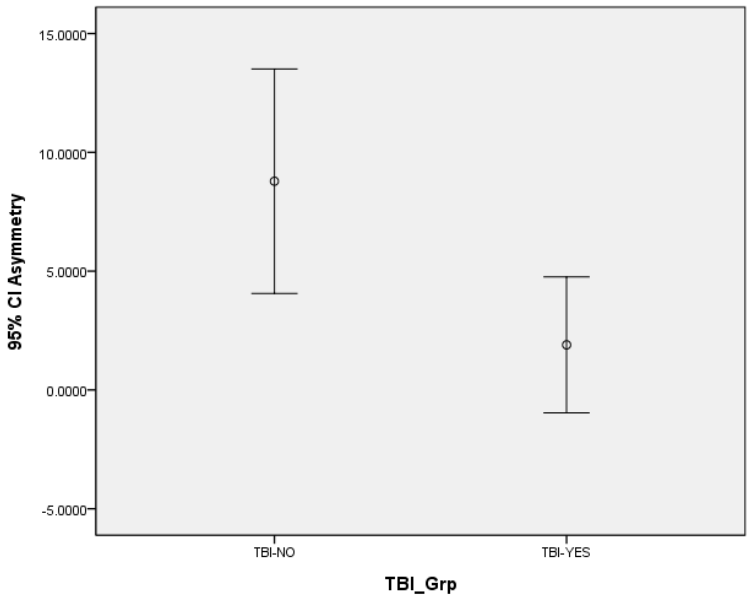

Figure 10. 95% Confidence Interval for the *asymmetry* variable on the Smooth Harmonic Acceleration (.32) subtest.

Smooth Harmonic Acceleration (.64) Results: One way ANOVA (using alpha of .05) showed significance for the *phase* variable both with the outlier: *F* (1, 74) = 8.23, *p* = .005 (η^2 = .10, i.e., 10% of the variability in the outcome is attributable to between-group differences) and without the outlier: *F* (1, 73) = 10.73, *p* = .002 (η^2 = .126, i.e., 12.6% of the variability in the outcome is attributable to between-group differences). The non-TBI group obtained a higher mean both with and without the outlier (*M* = 8.38, *SD* = 5.74) as opposed to the BI-TBI group mean with the outlier (*M* = -.192, *SD* = 14.62) or without the outlier (*M* = 1.31, *SD* = 10.16).

A Mann-Whitney non-parametric analogue to the two-group ANOVA was performed and commensurate with the findings for the ANOVA, there were significant between-group differences on the ranks for *phase* with the outlier: *Z* = -3.76, *p* <.05 or without the outlier: *Z* = -3.67, *p* < .05.

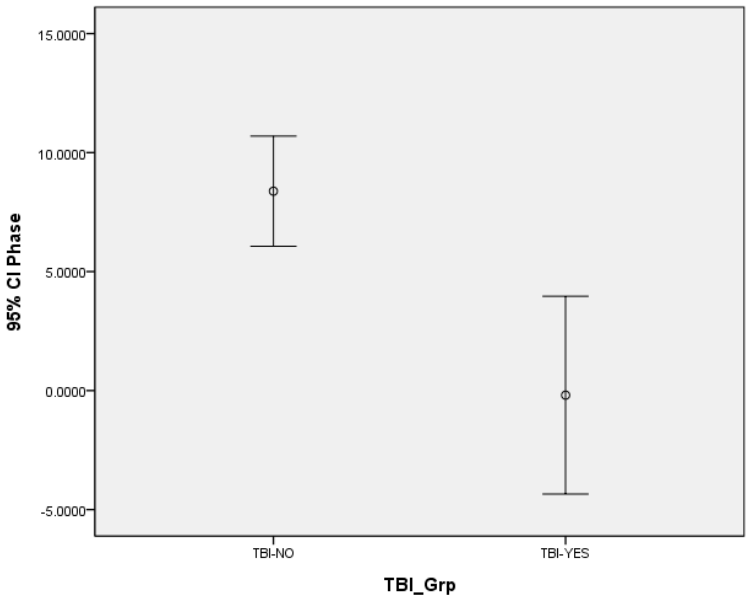

Figure 11. 95% Confidence Interval for the *phase* variable on the Smooth Harmonic Acceleration (.64) subtest (with outlier).

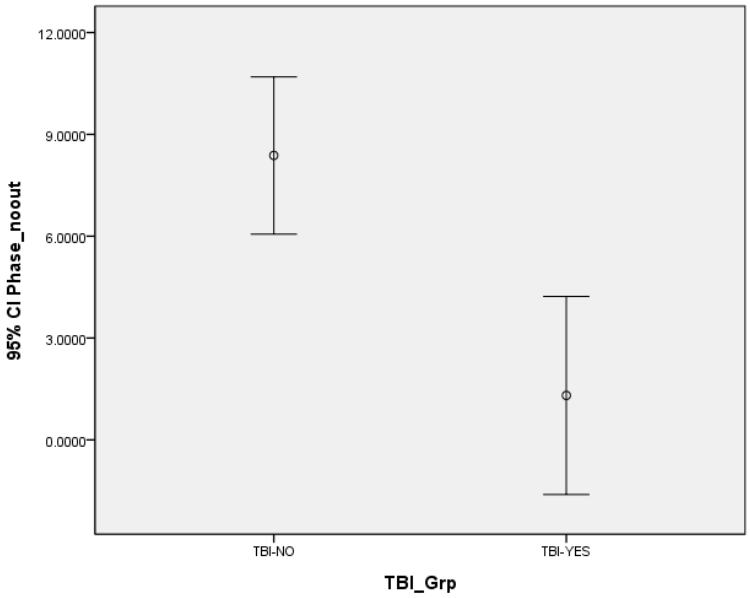

Figure 12. 95% Confidence Interval for the *phase* variable on the Smooth Harmonic Acceleration (.64) subtest (without outlier).

Smooth Harmonic Acceleration (1.75) Results: A one-way ANOVA using alpha of .05 showed significance was found for *gain average: F* (1, 70) = 9.60, *p* = .003 (η^2 = .121, i.e., 12.1% of the variability in the outcome is attributable to between-group differences). The non-TBI group obtained a higher mean (*M* = .92, *SD* = .11) as opposed to the TBI group mean (*M* = .77, *SD* = .22). Between-group differences were also found for *phase: F* (1, 70) = 13.24, *p* = .001 (η^2 = .159, i.e., 15.9% of the variability in the outcome is attributable to between-group differences). The non-TBI group obtained a higher mean (*M* = 11.70, *SD* = 10.83) as opposed to the TBI group mean (*M* = 3.11, *SD* = 8.88).

The Mann-Whitney non-parametric analogue to the two-group ANOVA was performed, and also showed significant between-group differences on the ranks for *gain average: Z* = -2.57, *p* = .01 and *phase***:** *Z* = -3.17, *p* = .002.

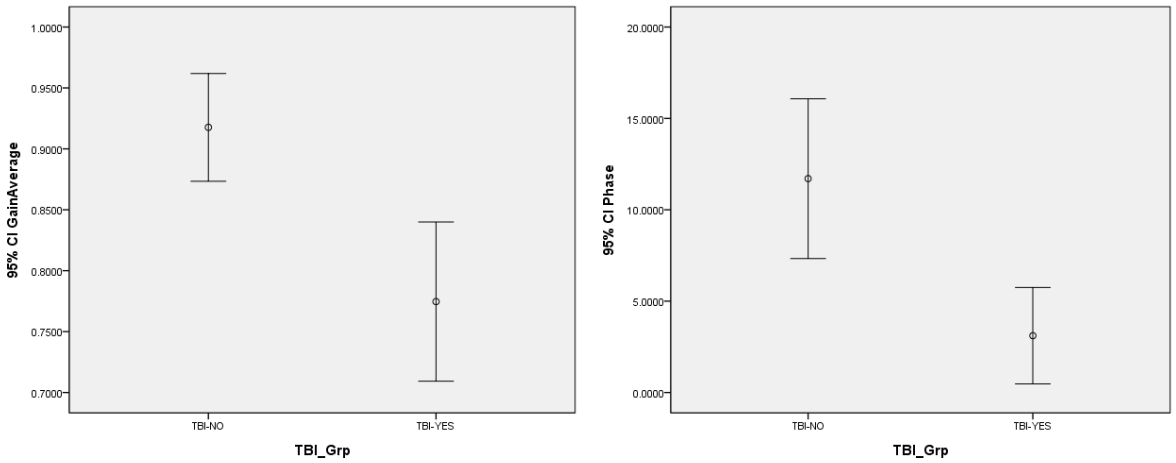

Figure 13. 95% Confidence Interval for the *gain average* and *phase* variables on the Smooth Harmonic Acceleration (1.75) subtest.

Saccades (Horizontal and Vertical)

Description: Saccades are rapid movements of the eye in response to a change in a visual stimulus. In the horizontal and vertical saccade subtests, a visual stimulus (laser dot) projected on the wall of the NOTC enclosure jumped back and forth or up and down. Saccades (initial rapid eye movements toward the target stimulus) and corrective saccades (small "adjustments" following the initial rapid eye movement) were measured and recorded. The rotary chair did not move during this subtest and the participant was instructed to follow the red light back and forth or up and down. *Left eye accuracy, right eye accuracy, undershoot, overshoot, latency, and velocity* variables were analyzed for this subtest.

Saccade Horizontal Results: A one-way ANOVA (alpha .05) showed significantly different between-group results for *left eye accuracy*: F (1, 75) = 8.65, p = .004 (η^2 = .103, i.e., 10.3% of the variability in the outcome is attributable to between-group differences). The non-TBI group obtained a higher mean (M = 91.64, SD = 4.95) as opposed to the BI-TBI group mean (M = 84.33, SD = 12.14). Statistical significance was also realized for: *right eye accuracy: F* (1, 75) = 6.17, p = .015 (η^2 = .076, i.e., 7.6% of the variability in the outcome is attributable to between-group differences). The non-TBI group obtained a higher mean (M = 91.74, SD = 4.72) as opposed to the BI-TBI group mean (M = 85.73, SD = 11.82).

The Mann-Whitney non-parametric analogue to the two-group ANOVA was performed given the heterogeneous variances and data point outliers. In accordance with the results of ANOVA, significance was found for *left eye accuracy: Z* = -2.75, p = .006 and *right eye accuracy: Z* = -2.37, p = .018

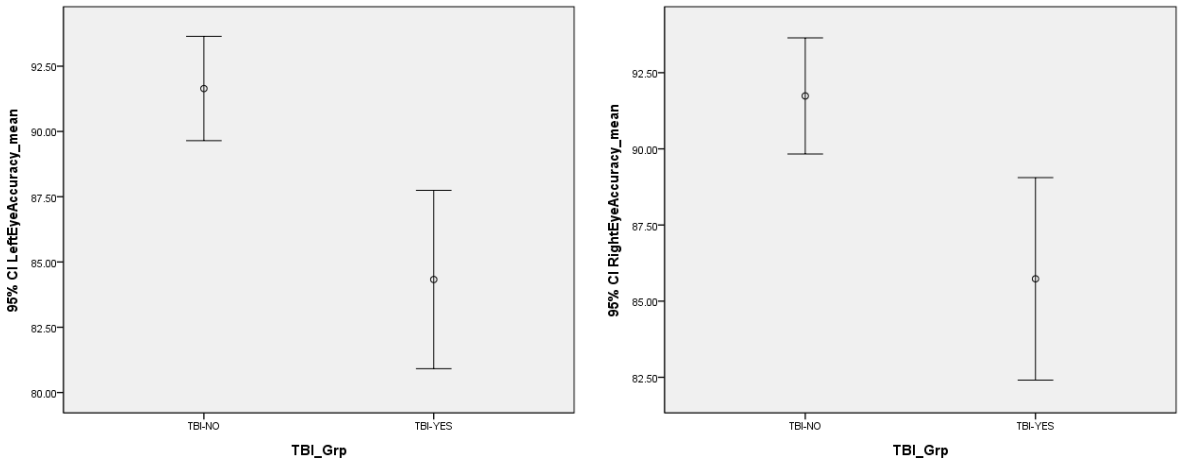

Figure 14. 95% Confidence Interval for the *left eye accuracy* and *right eye accuracy* variables on the Saccade Horizontal subtest.

One way ANOVA using alpha of .05 showed significant between-group differences for all of the outcomes of *undershoot* (right eye moving right (RR), right eye moving left (RL), left eye moving right (LR), left eye moving left (LL)).

RR undershoot: F (1, 84) = 34.0, p < .05 with 28.8% of the variability in the outcome attributable to between-group differences. The TBI group obtained a higher mean (M = 29.95, SD = 21.56) as opposed to the non-TBI group mean (M = 5.02, SD = 4.16).

RL undershoot: F (1, 84) = 20.07, p < .05 with 19.3% of the variability in the outcome attributable to between-group differences, The TBI group obtained a higher mean (M = 22.18, SD = 20.15) as opposed to the non-TBI group mean (M = 4.19, SD = 4.96).

LR undershoot: F (1, 84) = 23.31, $p < .05$ with 21.7% of the variability in the outcome attributable to between-group differences, The TBI group obtained a higher mean (M = 26.54, SD = 23.08) as opposed to the non-TBI group mean (M = 4.47, SD = 4.06).

LL undershoot: F (1, 84) = 30.27, $p < .05$ with 26.5% of the variability in the outcome attributable to between-group differences, The TBI group obtained a higher mean (M = 30.94, SD = 22.33) as opposed to the non-TBI group mean (M = 6.26, SD = 7.0).

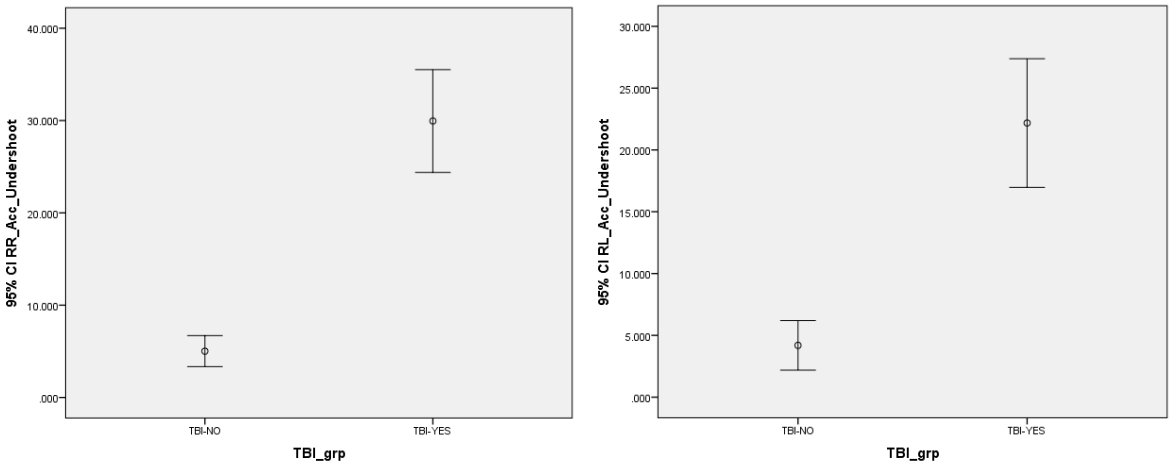

Figure 15. 95% Confidence Interval for the *RR undershoot* and *RL undershoot* variables on the Saccade Horizontal subtest.

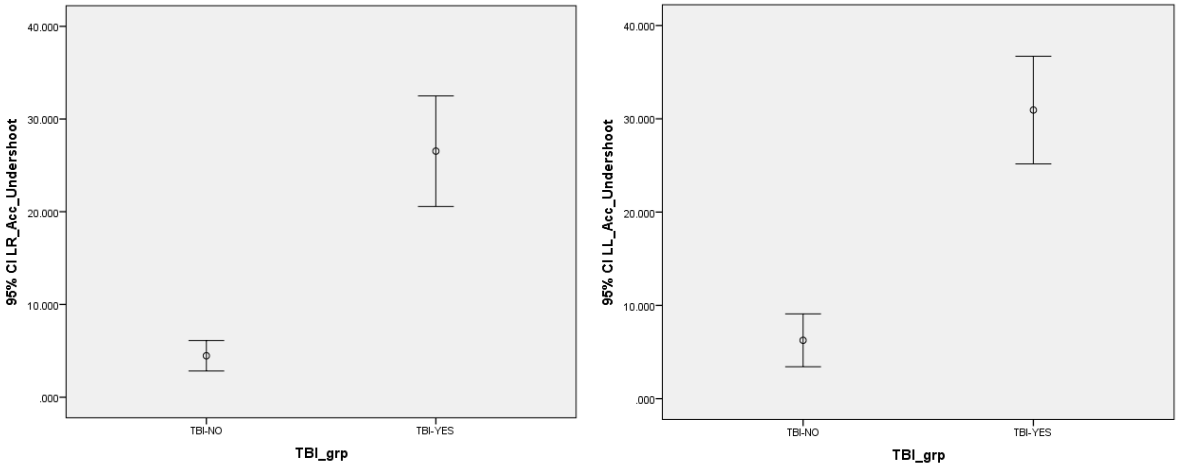

Figure16. 95% Confidence Interval for the *LR undershoot* and *LL undershoot* variables on the Saccade Horizontal subtest.

One way ANOVA using alpha of .05 did not reveal any significant between-group differences for any of the *overshoot* conditions (right eye moving right (RR), right eye moving left (RL), left eye moving right (LR), left eye moving left (LL)).

Horizontal saccade testing disclosed that the BI-TBI groups displayed a statistically significant higher latency average than that of the non-TBI group disclosing that the eye takes a greater amount of time to start moving after the stimulus has moved.

Significant between-group differences were found for all of the outcomes of latency (*left eye moving right (LR), left eye moving left (LL), right eye moving right (RR), right eye moving left (RL), and mean latency).*

LR latency: F (1, 84) = 6.45, *p* = .013 with 7.1% of the variability in the outcome due to between-group differences, The TBI group obtained a higher mean (*M* = .192, *SD* = .039) as opposed to the non-TBI group mean (*M* = .169, *SD* = .039).

LL latency: F (1, 84) = 7.71, *p* = .007 with 8.4% of the variability in the outcome due to between-group differences, The TBI group obtained a higher mean (*M* = .187, *SD* = .041) as opposed to the non-TBI group mean (*M* = .162, *SD* = .034).

RR latency: F (1, 84) = 7.73, *p* = .007 with 8.4% of the variability in the outcome due to between-group differences, The TBI group obtained a higher mean (*M* = .191, *SD* = .038) as opposed to the non-TBI group mean (*M* = .166, *SD* = .041).

RL latency: F (1, 84) = 7.5, *p* = .008 with 8.2% of the variability in the outcome due to between-group differences, The TBI group obtained a higher mean (*M* = .189, *SD* = .043) as opposed to the non-TBI group mean (*M* = .164, *SD* = .033).

Mean latency: F (1, 84) = 7.85, *p* = .006 with 8.5% of the variability in the outcome due to between-group differences, The TBI group obtained a higher mean (*M* = .19, *SD* = .039) as opposed to the non-TBI group mean (*M* = .165, *SD* = .035).

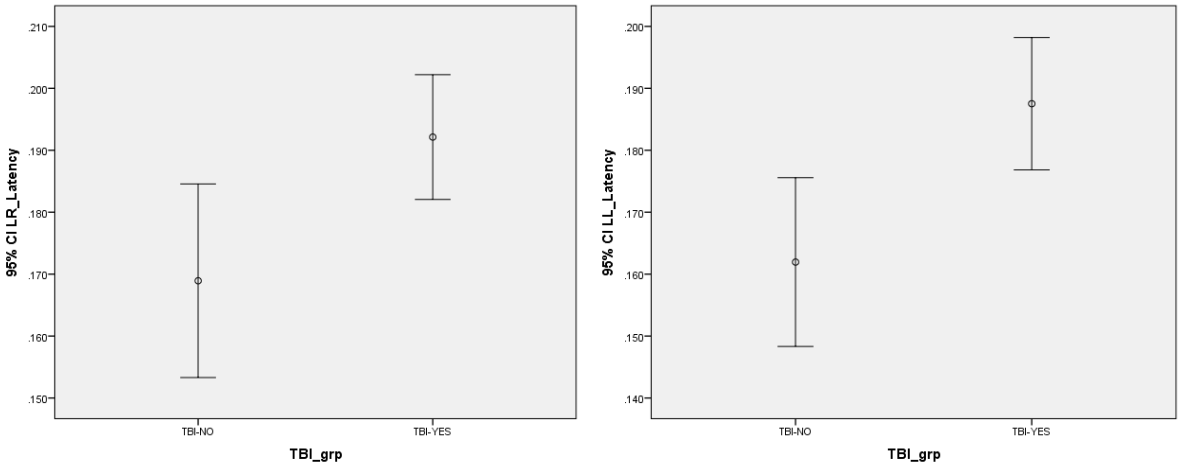

Figure 17. 95% Confidence Interval for the *LR latency* and *LL latency* variables on the Saccade Horizontal subtest.

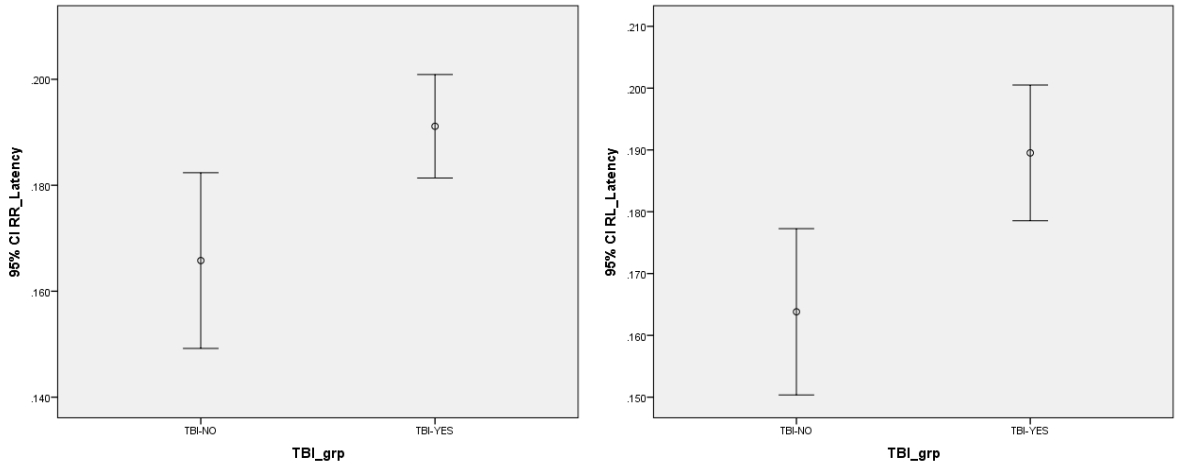

Figure 18. 95% Confidence Interval for the *RR latency* and *RL latency* variables on the Saccade Horizontal subtest.

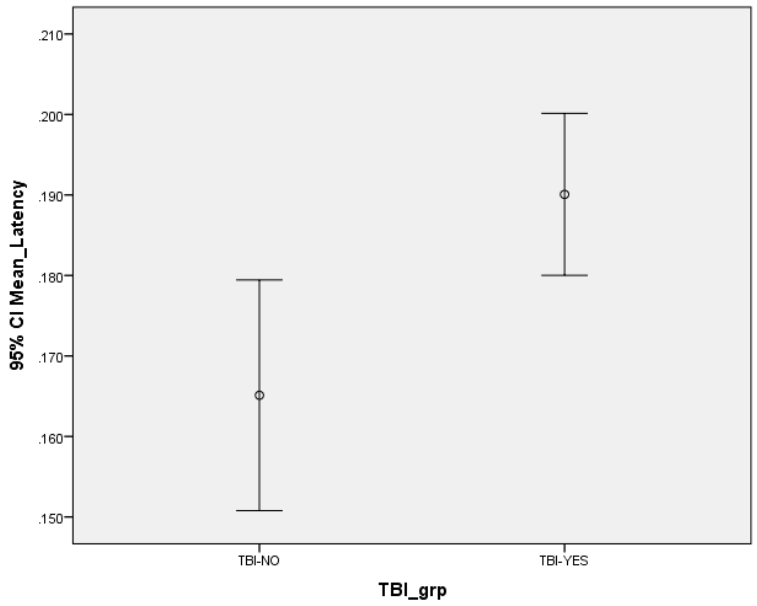

Figure 19. 95% Confidence Interval for the *mean latency* variable on the Saccade Horizontal subtest.

The peak velocity or speed at which the eye reaches target was also shown to be significantly slower in that of the BI-TBI group than that of the non-TBI group in some instances. One way ANOVA using alpha of .05 revealed a significant between-group difference for the *left eye peak velocity* (F (1, 75) = 4.53, p = .037) variable. No between-group difference was seen for *right eye peak velocity*.

For the *left eye peak velocity* variable, the initial eye movement was less accurate in the BI-TBI group and is assumed to be caused by undershooting the target as there shows to be no statistical significance in over shooting the target. After the corrective saccade took place and the eye came to its final resting place on the target, the BI-TBI group was less accurate at the final resting place of the eye.

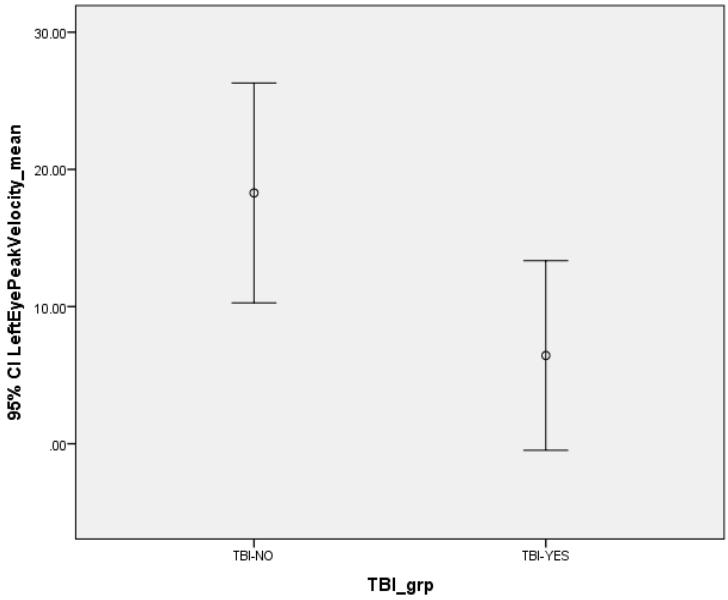

Figure 20. 95% Confidence Interval for the *left eye peak velocity* variable on the Saccade Horizontal

Saccade Vertical Results: No statistical significance was found for the between-group variables of *left eye accuracy* or *right eye accuracy* when conducting the one way ANOVA (using alpha of .05). A large effect size was obtained for *left eye accuracy*: F (1, 74) = 3.47, p = .067 (η^2 = .045, i.e., 4.5% of the variability in the outcome is attributable to between-group differences). Though not significant, the non-TBI group obtained a higher mean (M = 101.24, SD = 14.84) as opposed to the BI-TBI group mean (M = 93.51, SD = 18.21). Mann –Whitney analysis revealed the same non-significant results as ANOVA.

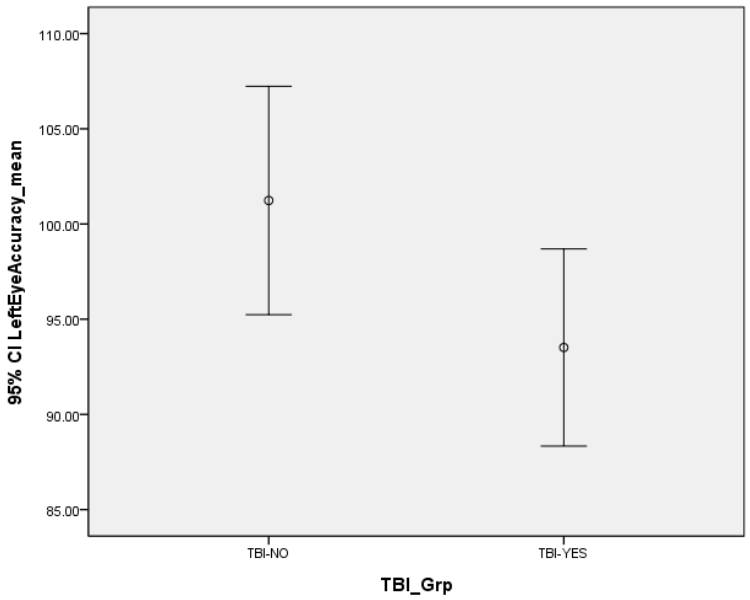

Figure 21. 95% Confidence Interval for the *left eye accuracy* variable on the Saccade Vertical subtest.

Statistically significant between-group differences were found for all of the outcomes of *undershoot* (right eye moving right (RR), right eye moving left (RL), left eye moving right (LR), left eye moving left (LL)).

LR undershoot: F (1, 83) = 19.72, $p < .05$ ($\eta^2 = .192$, i.e., 19.2 of the variability in the outcome is attributable to between-group differences, The TBI group obtained a higher mean (*M* = 37.39, *SD* = 21.78) as opposed to the non-TBI group mean (*M* = 17.14, *SD* = 12.10).

LL undershoot: F (1, 83) = 10.47, $p = .002$ ($\eta^2 = .112$, i.e., 11.2% of the variability in the outcome is attributable to between-group differences, The TBI group obtained a higher mean (*M* = 23.87, *SD* = 20.56) as opposed to the non-TBI group mean (*M* = 10.29, *SD* = 8.67).

RR undershoot: F (1, 83) = 12.55, $p = .001$ ($\eta^2 = .131$, i.e., 13.1% of the variability in the outcome is attributable to between-group differences, The TBI group obtained a higher mean (*M* = 33.52, *SD* = 20.96) as opposed to the non-TBI group mean (*M* =17.88, *SD* = 12.23).

RL undershoot: F (1, 83) = 10.9, $p = .001$ ($\eta^2 = .116$, i.e., 11.6% of the variability in the outcome is attributable to between-group differences, The TBI group obtained a higher mean (*M* = 22.07, *SD* = 21.7) as opposed to the non-TBI group mean (*M* = 7.6, *SD* = 7.58).

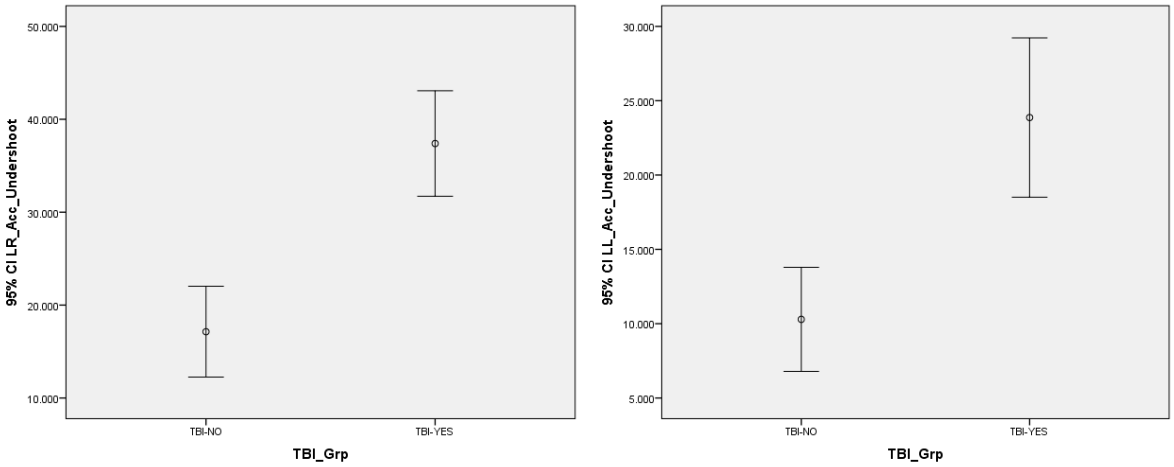

Figure 22. 95% Confidence Interval for the *LR undershoot* and *LL undershoot* variables on the Saccade Vertical subtest.

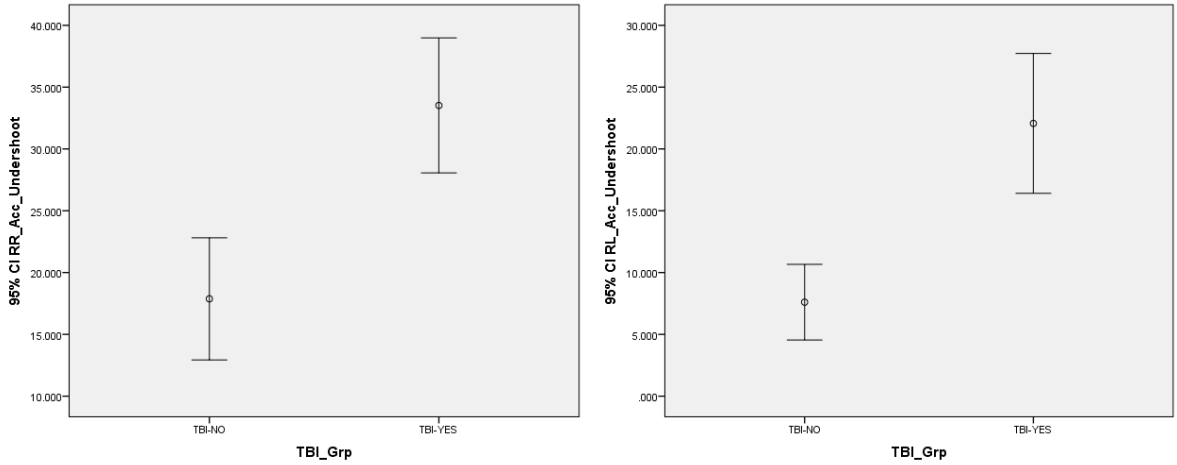

Figure 23. 95% Confidence Interval for the *RR undershoot* and *RL undershoot* variables on the Saccade Vertical subtest.

Statistically significant between-group differences were found for all of the *overshoot* outcomes except *RL overshoot* ($p = .290$).

LR overshoot: F (1, 83) = 17.28, $p < .05$ ($\eta^2 = .172$, i.e., 17.2% of the variability in the outcome is attributable to between-group differences. The non-TBI group obtained a higher mean (M = 13.95, SD = 15.93) as opposed to the TBI group (M = 4.46, SD = 5.0).

LL overshoot: F (1, 83) = 4.08, $p = .047$ ($\eta^2 = .047$, i.e., 4.7% of the variability in the outcome is attributable to between-group differences. The non-TBI group obtained a higher mean (M = 11.12, SD = 13.53) as opposed to the TBI group (M = 6.24, SD = 8.48).

RR overshoot: F (1, 83) = 8.17, *p* = .005 (η^2 = .09, i.e., 9% of the variability in the outcome is attributable to between-group differences. The non-TBI group obtained a higher mean (*M* = 12.65, *SD* = 15.73) as opposed to the TBI group (*M* = 5.75, *SD* = 6.62).

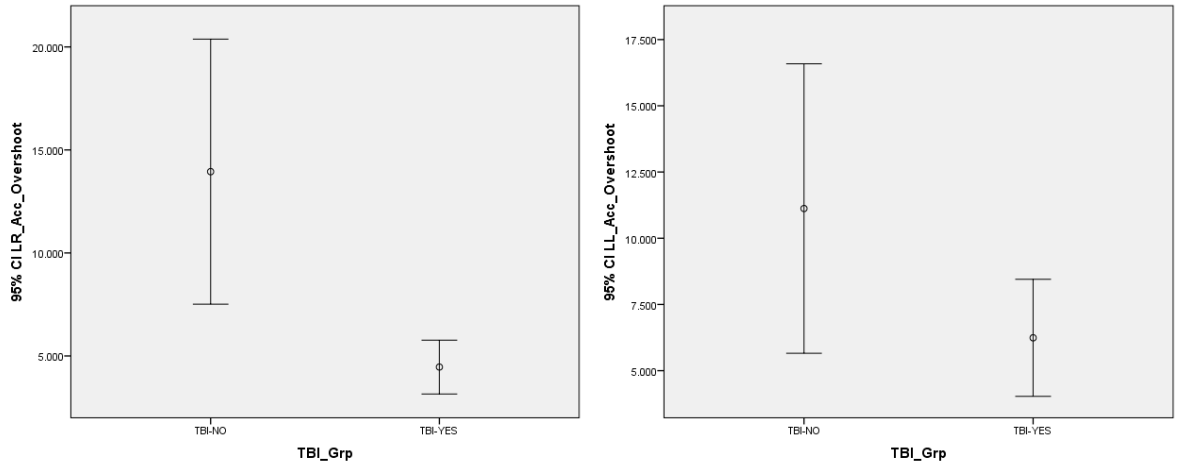

Figure 24. 95% Confidence Interval for the *LR overshoot* and *LL overshoot* variables on the Saccade Vertical subtest.

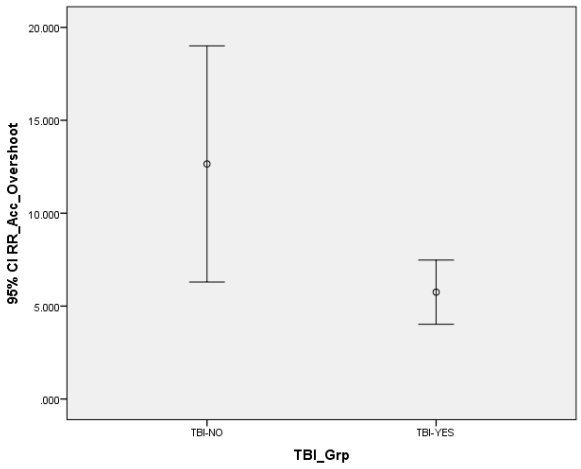

Figure 25. 95% Confidence Interval for the *RR overshoot* variable on the Saccade Vertical subtest.

Analysis of the Saccade Vertical *latency* variable revealed that the BI-TBI groups displayed a statistically significant higher latency average than that of the non- TBI group; in other words, the eye takes a greater amount of time to start moving after the stimulus has moved. Statistically significant between-group differences were found for all of the latency outcomes except *LR latency* (p = .066). The significant results are as follows:

LL latency: F (1, 83) = 6.62, *p* = .012 (η^2 = .074, i.e., 7.4% of the variability in the outcome is attributable to between-group differences, The TBI group obtained a higher mean (*M* = .208, *SD* = .04) as opposed to the non-TBI group mean (*M* = .186, *SD* = .023).

RR latency: F (1, 83) = 4.56, *p* = .036 (η^2 = .052, i.e., 5.2% of the variability in the outcome is attributable to between-group differences, The TBI group obtained a higher mean (*M* = .214, *SD* = .054) as opposed to the non-TBI group mean (*M* = .19, *SD* = .027).

RL latency: F (1, 83) = 8.2, *p* = .005 (η^2 = .09, i.e., 9% of the variability in the outcome is attributable to between-group differences, The TBI group obtained a higher mean (*M* = .21, *SD* = .039) as opposed to the non-TBI group mean (*M* = .186, *SD* = .024).

Mean latency: F (1, 83) = 6.28, *p* = .014 (η^2 = .07, i.e., 7% of the variability in the outcome is attributable to between-group differences, The TBI group obtained a higher mean (*M* = .21, *SD* = .042) as opposed to the non-TBI group mean (*M* = .188, *SD* = .025).

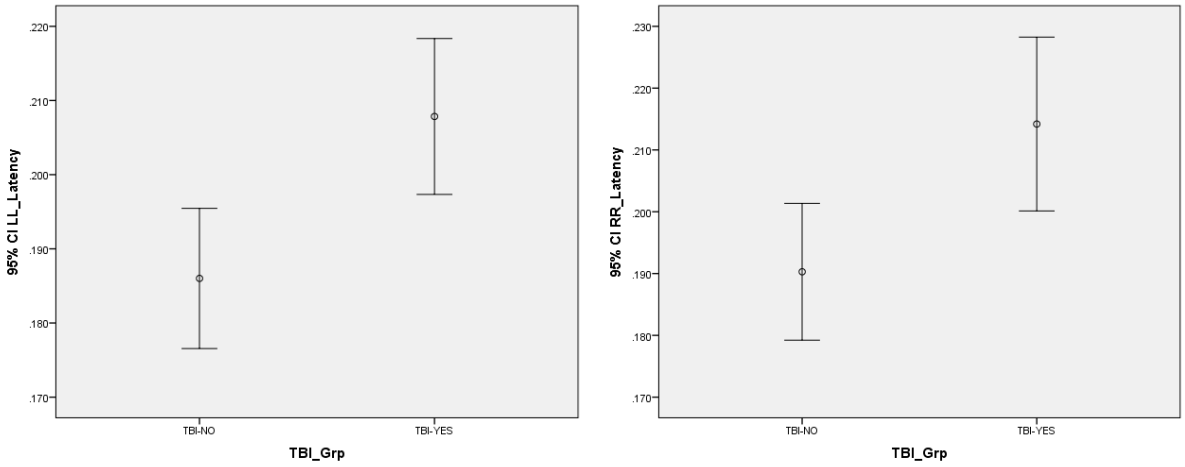

Figure 26. 95% Confidence Interval for the *LL latency* and *RR latency* variables on the Saccade Vertical subtest.

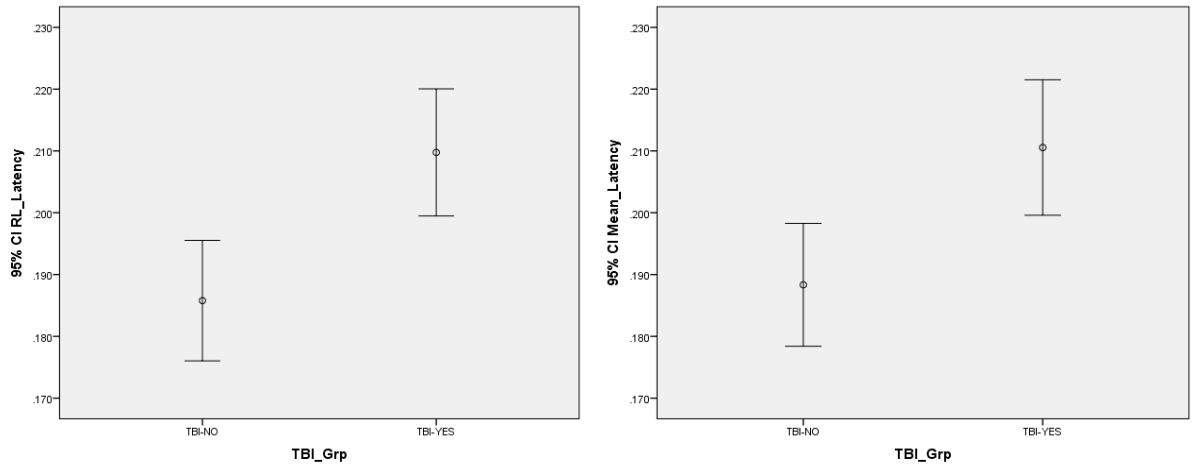

Figure 27. 95% Confidence Interval for the *RL latency* and *mean latency* variables on the Saccade Vertical subtest.

Analysis of the velocity subtest showed that the speed at which the eye reaches a visual target was slower for the BL-TBI group than it was for the non-TBI group. The initial eye movement was less accurate in the BI-TBI group; this is typically caused by undershooting the target, and is likely the case here as there shows to be no statistical significance in over shooting the target. After the corrective saccade takes place and the eye comes to its final resting place on the target, the BI-TBI group was less accurate at the final resting place of the eye.

Significance was found for both of the variables associated with velocity: *left eye peak velocity: F* (1, 74) = 5.36, *p* = .023. The non-TBI group obtained the higher mean (*M* = 19.93, *SD* = 31.97) as opposed to the TBI group (*M* = 3.02, *SD* = 29.29) and *right eye peak velocity: F* (1, 74) = 7.75, *p* = .007. The non-TBI group obtained the higher mean (*M* = 18.19, *SD* = 33.02) as opposed to the TBI group (*M* = -2.66, *SD* = 29.89).

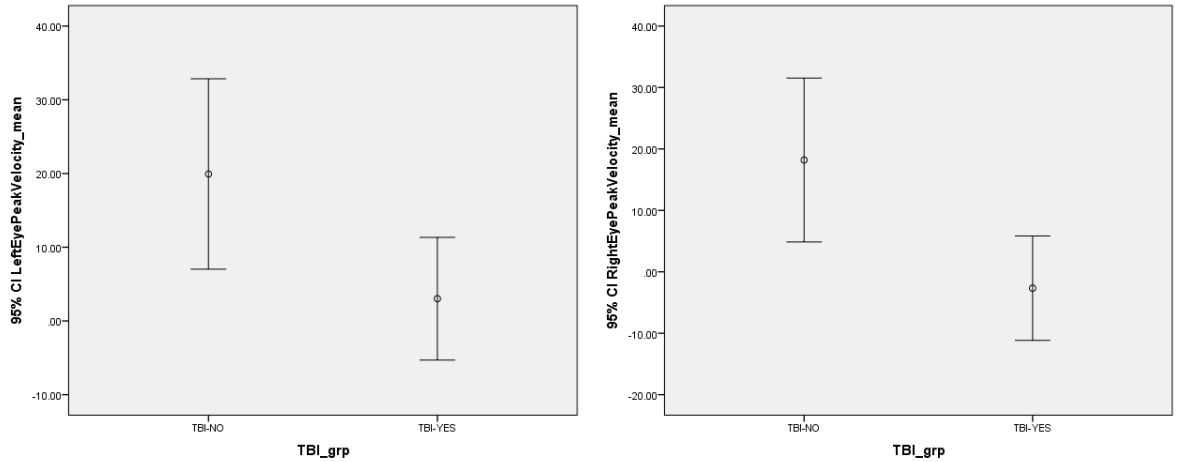

Figure 28. 95% Confidence Interval for the *left eye peak velocity* and *right eye peak velocity* variable on the Saccade Vertical subtest.

Saccadic testing disclosed abnormal accuracy, overall accuracy, latency and a high incidence of undershooting in the BI-TBI group. Most saccadic disorders are due to brainstem or cerebellar lesions. Overshoot or "hypometria, is the hallmark of cerebellar disease, and particularly is found in patients with damage to the fastigial nucleus, which is in the roof of the IVth ventricle" (Jacobson, 2008).

Smooth Pursuit Horizontal (0.1, 0.2, 0.4, and 0.71)

Description: Pursuit eye movement allows an individual to track a moving target so that it remains stable on the retina. In the Horizontal Smooth Pursuit subtest, the visual target (red laser light projected on the inner surface of the NOTC enclosure) was moved back and forth, left and right and the participant was asked to follow the target, keeping his/her head still. In the first subtest, the target was moved ±10 degrees at 0.10 Hz. Peak velocity of the target stimulus on the NOTC wall was 6.28 degrees per second. Three cycles, back and forth, were projected. The rotary chair did not move during this subtest and the participant was asked to follow the light as it moved back and forth while keeping their head still. The analyzed variables for each Smooth Pursuit Horizontal subtest (0.1, 0.2, 0.4, and 0.71) were *leftward gain, rightward gain, gain asymmetry, percent saccade, position gain*, and *position asymmetry*.

Smooth Pursuit Horizontal (0.1) Results: A one-way ANOVA was conducted on the Smooth Pursuit Horizontal (0.1) subtest, using an alpha level of 0.5. Statistical significance was found for the *percent saccade*: F (1, 74) = 10.53 p = .002 (η^2 = .125, i.e., 12.5% of the variability in the outcome is attributable to between-group differences). The TBI group obtained the higher mean (M = 19.79, SD = 11.55) as opposed to the non-TBI group mean (M = 11.68, SD = 7.39).

Given the outliers, and in lieu of deleting and/or transforming them, the non-parametric analogue to the two-group ANOVA was performed (Mann-Whitney test). As with the ANOVA, *percent saccade* yields significant between-group differences on the ranks: Z = -3.10, p = .002; however, now there are also significant differences on *asymmetry* (due to a large negative outlier): Z = -2.04, p = .042. The higher mean rank is associated with the non- TBI group.

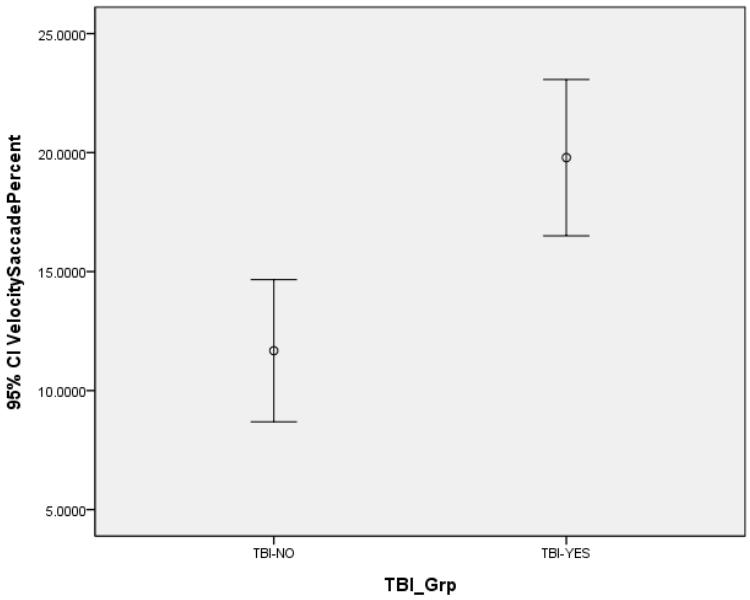

Figure 29. 95% Confidence Interval for *percent saccade* variable on the Smooth Pursuit Horizontal (0.1) subtest.

Smooth Pursuit Horizontal (0.2) Results: A one-way ANOVA with an alpha level of .05 yielded no significant differences between the non-TBI group and the BI-TBI group for any of the variables on the Smooth Pursuit Horizontal (0.2) subtest. The largest effect size was found for *percent saccade*: F (1, 74) = 3.43, p = .068 (η^2 = .044, i.e., 4.4% of the variability in the outcome is attributable to between-group differences). The BI-TBI group obtained the higher mean (M = 10.84, SD = 10.72) as opposed to the non-TBI group mean (M = 6.52, SD = 7.11).

Given the outliers for some of the groups (and in lieu of deleting the outliers and/or transforming the outcomes) the Mann-Whitney non-parametric analogue to the two-group ANOVA was performed. As opposed to the ANOVA, percent *saccade* yielded significant between-group differences on the ranks: Z = -2.08, p = .037 with the higher mean rank associated with the BI-TBI group.

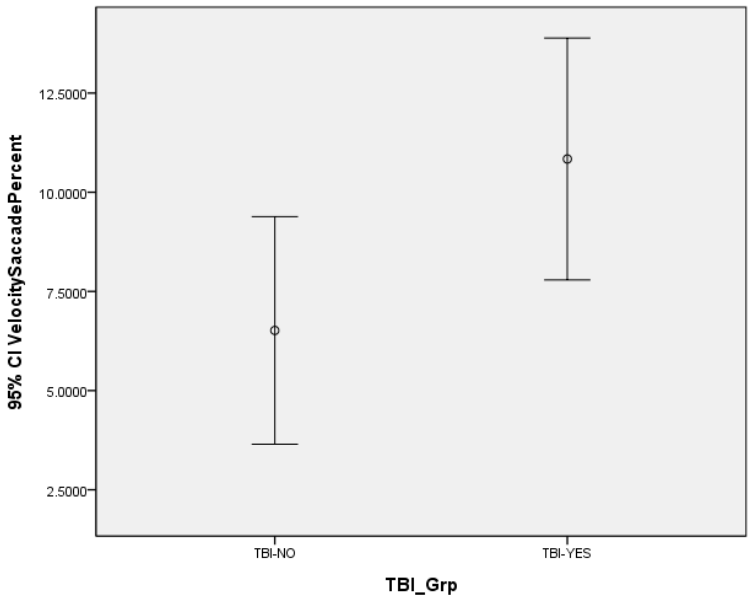

Figure 30. 95% Confidence Interval for *percent saccade* variable on the Smooth Pursuit Horizontal (0.2) subtest.

Smooth Pursuit Horizontal (0.4) Results: A one-way ANOVA with an alpha level of .05 yielded no significant differences between the non-TBI group and the BI-TBI group for any of the variables on the Smooth Pursuit Horizontal (0.4) subtest (Figure XX). The largest effect size was found for *position gain*: F (1, 72) = 1.54, p = .219 (η^2 = .021, i.e., 2.1% of the variability in the outcome is attributable to between-group differences). The TBI group obtained a slightly higher mean (M = 1.03, SD = 12) as opposed to the non-TBI group mean (M = 1.00, SD = .04).

Instead of deleting the outliers and/or transforming the outcomes, and due to the heterogeneous variances of the data, the Mann-Whitney non-parametric analogue to the two-group ANOVA was performed. As with the ANOVA, there were no significant between-group differences on the ranks for any of the outcomes.

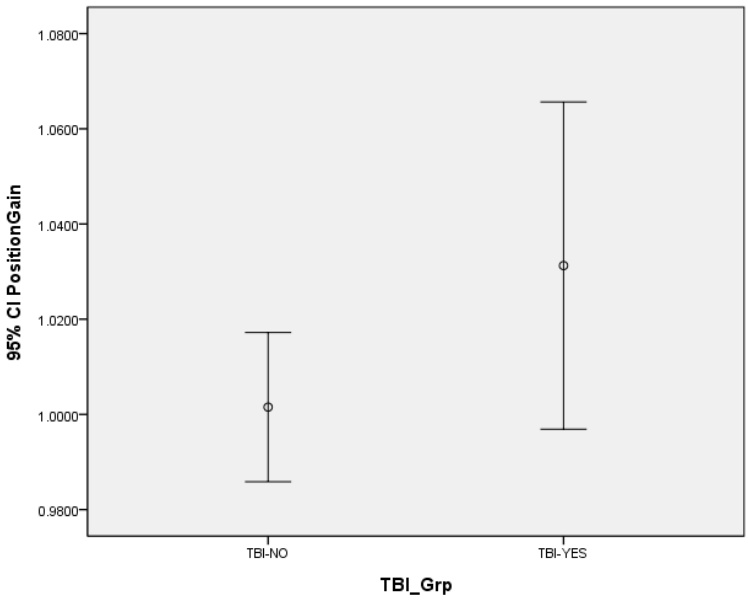

Figure 31. 95% Confidence Interval for *position gain* variable on the Smooth Pursuit Horizontal (0.4) subtest.

*Smooth Pursuit Horizontal (0.71) Result*s: A one-way ANOVA with an alpha level of .05 yielded no significant differences between the non-TBI group and the BI-TBI group for any of the variables on the Smooth Pursuit Horizontal (0.71) subtest. The largest effect size was found for *gain asymmetry*: F (1, 72) = .90, p = .346 (η^2 = .012, i.e., 1.2% of the variability in the outcome is attributable to between-group differences). The non-TBI group obtained a slightly higher mean (M = 2.05, SD = 7.08) as opposed to the BI-TBI group mean (M = -.03, SD = 9.83).

Due to heterogeneous variances, the Mann-Whitney non-parametric analogue to the two-group ANOVA was performed in lieu of deleting the outliers and/or transforming the outcomes. As with the ANOVA, there were no significant between-group differences on the ranks for any of the outcomes.

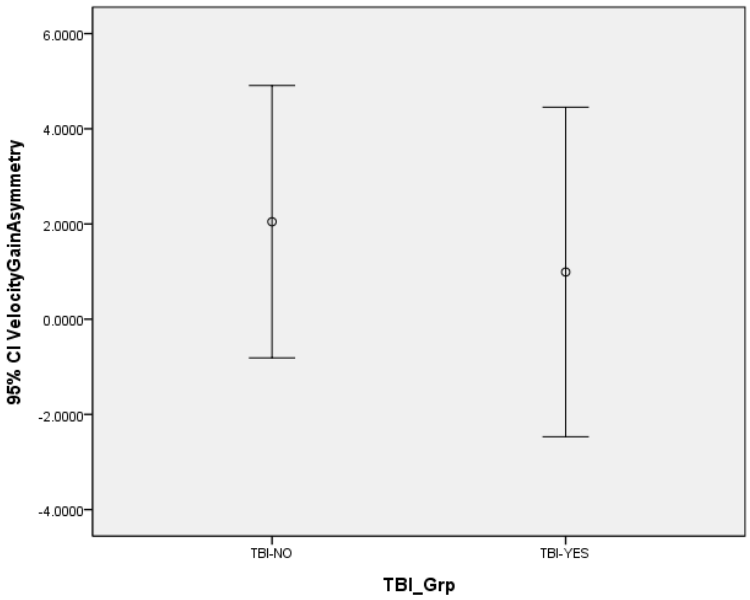

Figure 32. 95% Confidence Interval for *gain asymmetry* variable on the Smooth Pursuit Horizontal (0.71) subtest.

Smooth pursuit horizontal testing at the speed of .01 and .71 disclose a statistically significant difference in the percentage of saccades with the BL-TBI group having an abnormal amount of saccadic movement while tracking. This indicates that the BL-TBI group was not able to track a target with smooth movements at these speeds; instead used a saccadic movement to help track the moving target. An abnormal percent of saccades in the pursuit movement is suggestive of an abnormality in the central auditory system.

Smooth Pursuit Vertical

Description: In the Vertical Smooth Pursuit subtest, the visual target (red laser light projected on the inner surface of the NOTC enclosure) was moved back and forth, up and down and the volunteer is asked to follow target, keeping his/her head still. In the first subtest, the target was moved ±10 degrees at 0.10 Hz. Peak velocity of the target stimulus on the NOTC wall was 6.28 degrees per second. Three cycles, back and forth, were projected. The rotary chair did not move during this subtest and the participant was asked to follow the light as it moved up and down while keeping their head still. The analyzed variables for each Smooth Pursuit Vertical subtest (0.1, 0.2, 0.4, and 0.71) *were upward gain, downward gain, gain asymmetry, percent saccade*, *position gain*, and *position asymmetry*.

Smooth Pursuit Vertical (0.1) Results: Between-group statistical significance for the following variables was found with an ANOVA using an alpha level of .05: *Downward gain: F* (1, 73) = 9.74, $p = .003$ ($\eta^2 = .118$, i.e., 11.8% of the variability in the outcome is attributable to between-group differences). The non-TBI group obtained a higher mean ($M = .936$, $SD = .09$) as opposed

to the BI-TBI group mean (*M* = .832, *SD* = .157). *Percent saccade:* *F* (1, 73) = 15.29, *p* < .05 (η^2 = .173, i.e., 17.3% of the variability in the outcome is attributable to between-group differences). The BI-TBI group obtained a higher mean (*M* = 31.02 *SD* = 12.74) as opposed to the non-TBI group mean (*M* = 18.82, *SD* = 13.11).
The Mann-Whitney non-parametric analogue to the two-group ANOVA was performed, and commensurate with the findings for the ANOVA, there were significant between-group differences on the ranks for *downward gain: Z* = -2.84 , *p* = .005 and *percent saccade:* *Z* = -3.75, *p* < .05.

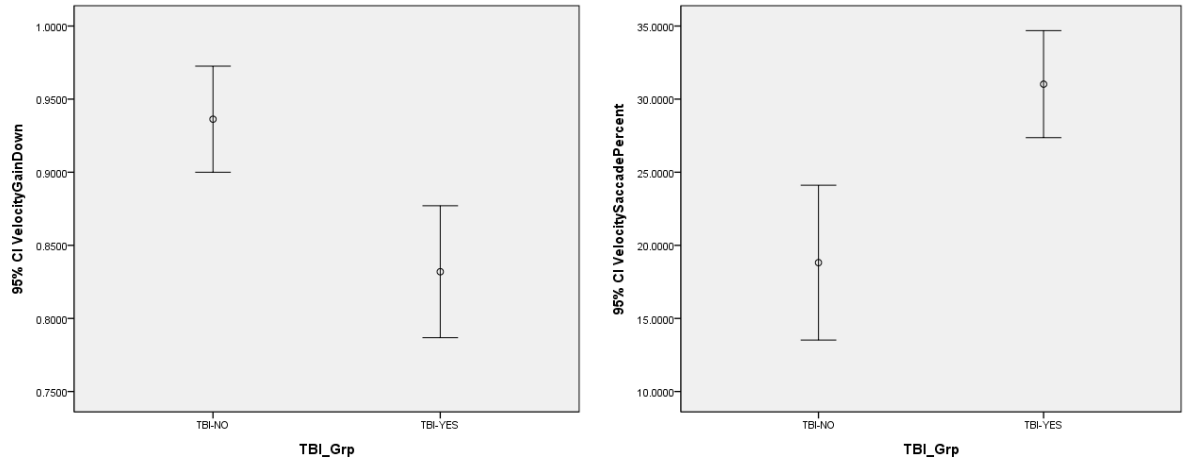

Figure 33. 95% Confidence Interval for *downward gain* and *percent saccade* variables on the Smooth Pursuit Vertical (0.1) subtest.

Smooth Pursuit Vertical (0.2) Results: A one-way ANOVA (using alpha of .05) showed no statistical significance for any of the conditions in Smooth Pursuit Vertical (0.2), although for the *position gain* variable some might use the problematic attribution of marginally significant: *F* (1, 67) = 3.49, *p* = .066 (η^2 = .049, i.e., 4.9% of the variability in the outcome is attributable to between-group differences). For the *position gain* variable, the BI-TBI group showed a slightly higher mean (*M* = .997, *SD* = .125 as opposed to the non-TBI group mean (*M* = .939, *SD* = .127). A similar conclusion might be drawn for *gain asymmetry*: *F* (1, 67) = 3.18, *p* = .079 (η^2 = .045), for which the BI-TBI group obtained a higher mean (*M* = 3.43, *SD* = 12.13) as opposed to the non-TBI group mean (*M* = -1.83, *SD* = 11.38).

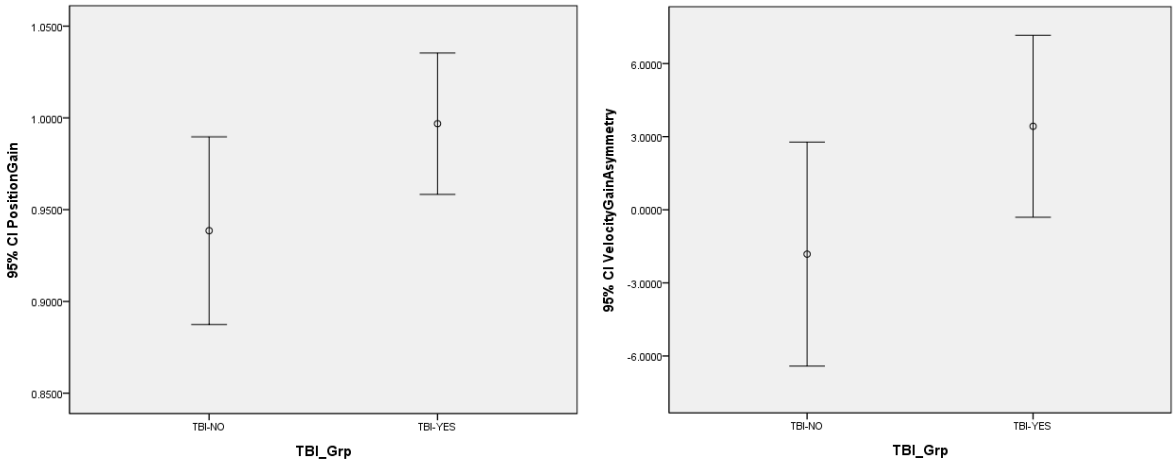

Figure 34. 95% Confidence Interval for *position gain* and *gain asymmetry* variables on the Smooth Pursuit Vertical (0.2) subtest.

Due to the heterogeneous variance and outliers in the data, the Mann-Whitney non-parametric analogue to the two-group ANOVA was performed. In opposition to the ANOVA, there were significant between-group differences on the ranks for *position gain***:** Z = -2.08, p = .037 and *gain asymmetry:* Z = -2.17, p = .03.

Smooth Pursuit Vertical (0.4) Results: There were no significant differences found when comparing groups with a one-way ANOVA using alpha of .05. The largest effect size was found for *position asymmetry*: F (1, 66) = 1.44, p = .235 (η^2 = .021, i.e., 2.1% of the variability in the outcome is attributable to between-group differences. Though not statistically significant, the non-TBI group obtained a higher mean (M = 1.07, SD = 7.02) as opposed to the TBI group mean (M = .32, SD = 5.0).

The Mann-Whitney non-parametric analogue to the two-group ANOVA was conducted due to the outliers and the heterogeneous variance of the data. As with the ANOVA, there were no significant between-group differences on any of the subtest variables.

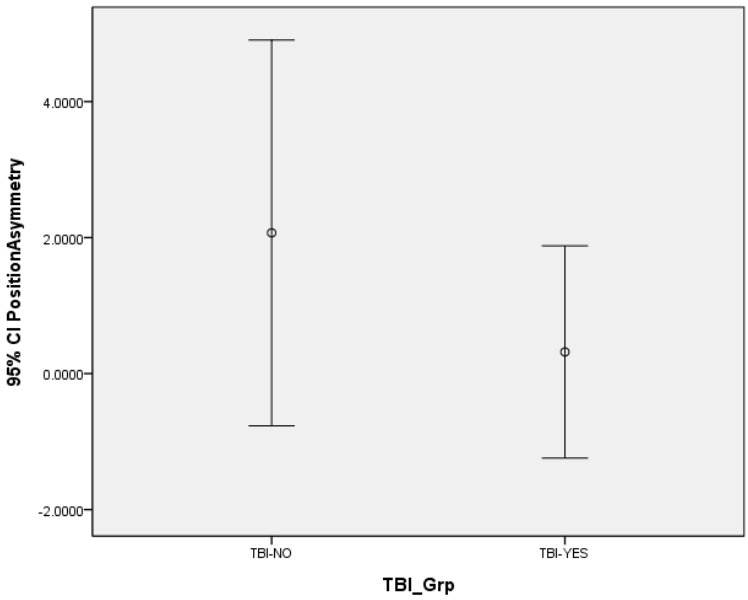

Figure 35. 95% Confidence Interval for the *position asymmetry* variable on the Smooth Pursuit Vertical (0.4) subtest.

Smooth Pursuit Vertical (0.71) Results: A one-way ANOVA (using alpha of .05) showed between group statistical significance for the *gain asymmetry* variable: F (1, 71) = 8.58, p = .005 (η^2 = .108, i.e., 10.8% of the variability in the outcome is attributable to between-group differences). The BI-TBI group demonstrated a higher mean value for *gain asymmetry* (M = 4.45, SD = 14.5) as opposed to the non-TBI group mean (M = -6.39, SD = 16.26). Results of the Mann-Whitney non-parametric test were consistent with the ANOVA and showed a significant between-group difference for the *gain asymmetry* variable: Z = -2.36, p = .018.

The next strongest effect, though not statistically significant, was for *upward gain*: F (1, 71) = 3.85, p = .054 (η^2 = .051, i.e., 10.8% of the variability in the outcome is attributable to between-group differences). The BI-TBI group obtained a higher mean (M = .75, SD = .22) as opposed to the non-TBI group mean (M = .646, SD = 215).

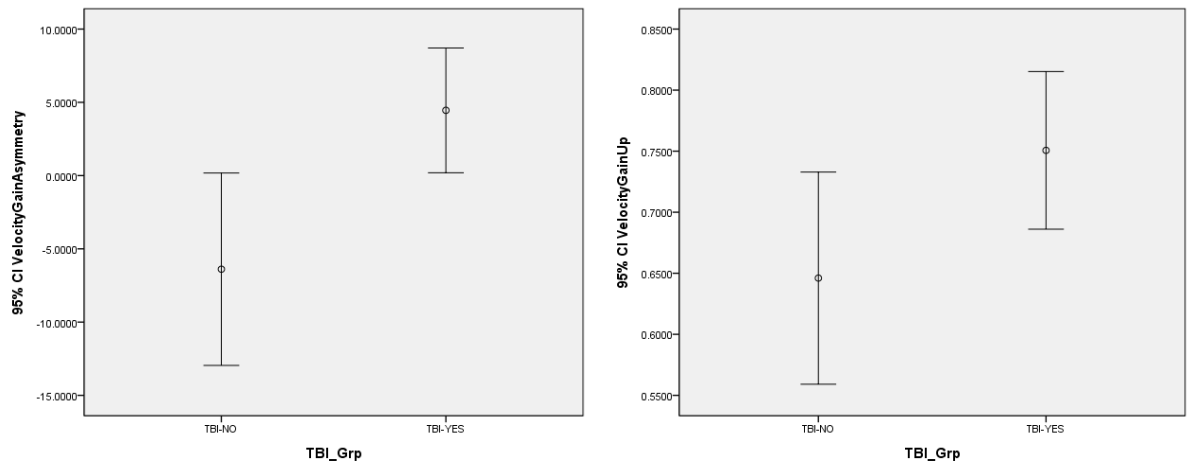

Figure 36. 95% Confidence Interval for the *asymmetry* and *upward gain* variables on the Smooth Pursuit Vertical (0.71) subtest.

Gaze Horizontal (Left and Right)

Description: The primary purpose of the Gaze Horizontal subtest was to detect nystagmus when the head is fixed and the eyes are gazing off center from the primary (straight ahead) gaze position. This test is designed to assess the central nervous system ocular motor system. The rotary chair did not move during this subtest, however, a red light came on in the center position for 3 seconds and then it came on again either to the right or to the left for 3 seconds. Participants were instructed to concentrate on keeping their eyes in the same position where the light was last seen and not to move their eyes until the light came back on in a new location. Participants were kept alert during the Gaze Horizontal subtest. One way the examiner maintained participant alertness was by asking the participant questions (e.g., mental arithmetic problems) and requiring responses following each question. Variables of interest for statistical analysis were: *horizontal fixation lights on, horizontal fixation lights off, vertical fixation lights on*, and *vertical fixation lights off*. The metric of interest was the number of nystagmus beats in each condition.

Gaze Horizontal (Left) Results: Statistical significance was found with a one-way ANOVA for *horizontal fixation lights off***:** F (1, 83) = 6.83, p = .011 (η^2 = .076, i.e., 7.6% of the variability in the outcome is attributable to between-group differences. The BI-TBI group obtained the higher mean (M = 3.56, SD = 6.27) as opposed to the non-TBI group mean (M = .13, SD = .46). There was also a significant finding for *vertical fixation lights on: F* (1, 83) = 4.44, p = .038 (η^2 = .051, i.e., 7.6% of the variability in the outcome is attributable to between-group differences). The BI-TBI group obtained the higher mean (M = .71, SD = .95) as opposed to the non-TBI group mean (M = .26, SD = .62).

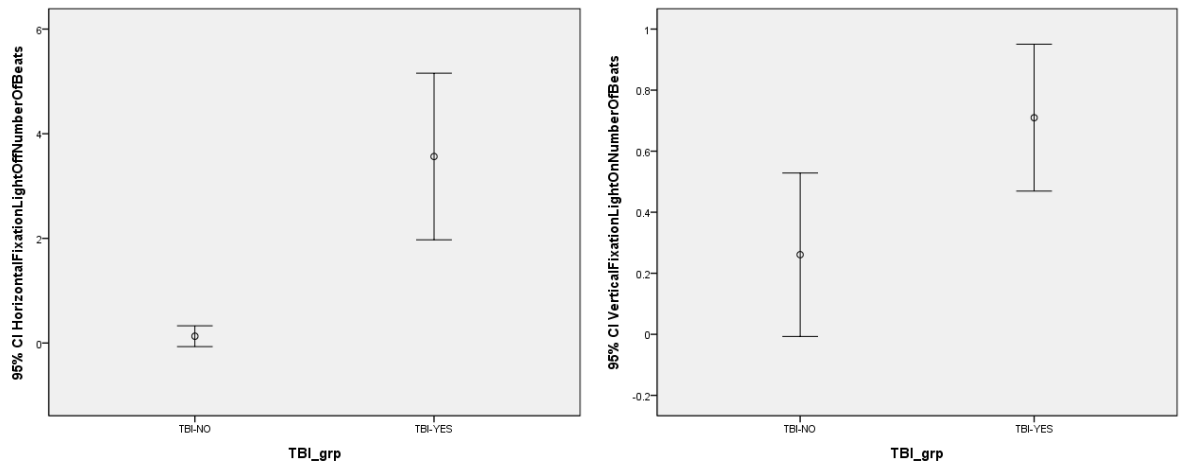

Figure 37. 95% Confidence Interval for the *horizontal fixation lights off* and *vertical fixation lights on* variables on the Gaze Horizontal (Left) subtest.

Gaze Horizontal (Right) Results: Statistical significance was found with a one-way ANOVA for *horizontal fixation lights on: F* (1, 83) = 7.61, *p* = .007 (η^2 = .084, i.e., 8.4% of the variability in the outcome is attributable to between-group differences. The BI-TBI group obtained the higher mean (*M* = .61, *SD* = 1.06) whereas there was no variation (hence, this result should be interpreted with caution) for the non-TBI group (*M* = 0, *SD* = 0). There was also a significant finding for *vertical fixation lights on*: *F* (1, 83) = 5.64, *p* = .02 (η^2 = .064, i.e., 6.4% of the variability in the outcome is attributable to between-group differences). The BI-TBI group obtained the higher mean (*M* = 1.1, *SD* = 1.34) as opposed to the non-TBI group (*M* = .39, *SD* = .78).

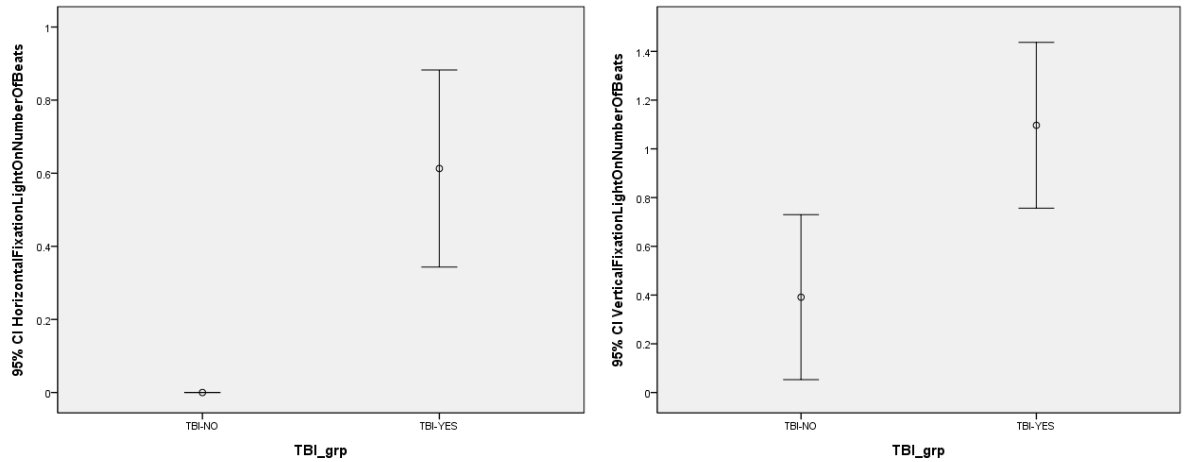

Figure 38. 95% Confidence Interval for the *horizontal fixation lights on* and *vertical fixation lights on* variables on the Gaze Horizontal (Right) subtest

Gaze Vertical (Up and Down)

Description: The primary purpose of the Gaze Vertical subtest was to detect nystagmus when the head is fixed and the eyes are gazing off center from the primary (straight ahead) gaze position. This test is designed to assess the central nervous system ocular motor system. The rotary chair did not move during this subtest, however, a red light came on in the center position for 3 seconds and then it came on again either above or below the center position for 3 seconds. Participants were instructed to concentrate on keeping their eyes in the same position where the light was last seen and not to move their eyes until the light came back on in a new location. Participants were kept alert during the Gaze Vertical subtest. One way the examiner maintained participant alertness was by asking the participant questions (e.g., mental arithmetic problems) and requiring responses following each question. Variables of interest for statistical analysis were: *horizontal fixation lights on, horizontal fixation lights off, vertical fixation lights on*, and *vertical fixation lights off*. The metric of interest was the number of nystagmus beats in each condition.

Results: ANOVA yielded no statistically significant between-group differences for the Gaze Vertical Up subtest. The largest effect size was found for *horizontal fixation lights on* which was very small (r^2 = 1.1%). Similarly, there were no statistically significant between-group differences for the Gaze Vertical Down subtests. The largest effect size was found for *vertical fixation lights on* which was very small (r^2 = 1.3%).

Optokinetic Trapezoidal (20, 40, and 60)

Description: The Optokinetic Trapezoidal subtest was a tracking task similar to the smooth pursuit test except that instead of tracking a single point projected on the NOTC wall, a rotating visual field consisting of a large number of diffuse targets or vertical stripes was displayed. Optokinetic nystagmus testing was conducted in a whole body rotational chair in a darkened room. The chair was in a fixed position, pointed away from the door to prevent any visual cues from affecting the volunteer's perceptions. The rotating visual stimulus (a large number of diffuse targets) was protected on the surface of the darkened room, triggering the optokinetic reflex and giving the perception of rotation known as circular vection. The subject was asked look into the files of moving targets. Testing was completed at 20, 40, and 60 degrees per second with targets moving first to the right and then to the left.

Optokinetic Trapezoidal (20) Results: A one-way ANOVA (using alpha of .05) showed significance for *average gain:* $F(1, 71) = 13.43$, $p < .05$ (η^2 = .159, i.e., 15.9% of the variability in the outcome is attributable to between-group differences). The non-TBI group obtained a higher mean (M = .878, SD = .10) as opposed to the BI-TBI group mean (M = .774, SD = .123).

A Mann-Whitney analysis was performed, and commensurate with the findings for the ANOVA, there were significant between-group differences on the ranks for *average gain: Z* = -3.55, *p*<.05.

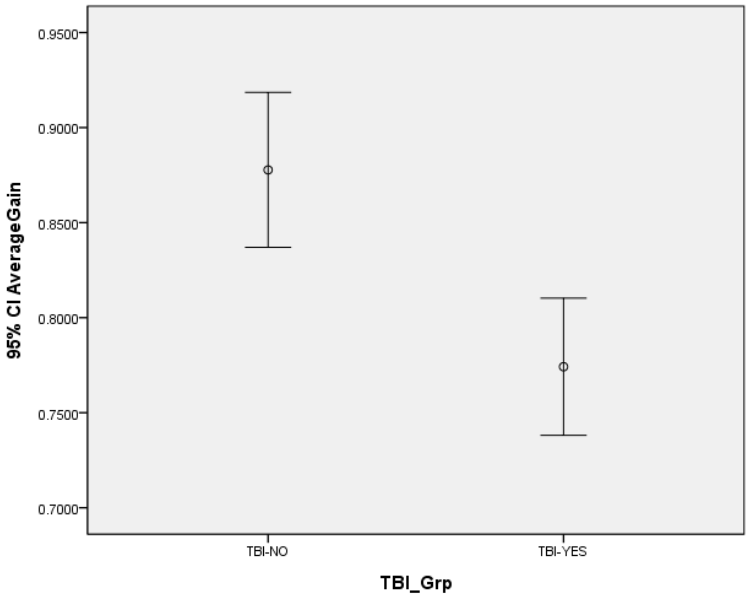

Figure 39. 95% Confidence Interval for the *average gain* variable on the Optokinetic Trapezoidal (20) subtest.

Optokinetic Trapezoidal (40) Results: As with the previous subtest, a one-way ANOVA using alpha of .05 showed significance for *average gain:* F (1, 71) = 8.81, p = .004 (η^2 = .110, i.e., 11% of the variability in the outcome is attributable to between-group differences). The non-TBI group obtained a higher mean (M = .724, SD = .146) as opposed to the BI-TBI group mean (M = .619, SD = .144). A Mann-Whitney was performed, and also showed significant between-group differences on the ranks for *average gain: Z* = -2.78, *p* = .005.

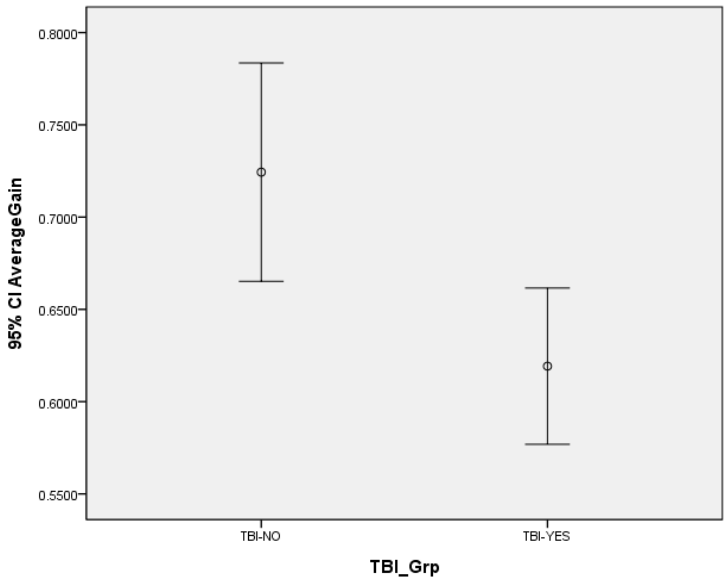

Figure 40. 95% Confidence Interval for the *average gain* variable on the Optokinetic Trapezoidal (40) subtest.

Optokinetic Trapezoidal (60) Results: As with *Optokinetic Trapezoidal (20)* and *(40),* significance was found for *average gain:* F (1, 70) = 7.76, p = .007 (η^2 = .10, i.e., 10% of the variability in the outcome is attributable to between-group differences) with a one-way ANOVA. The non-TBI group obtained a higher mean (M = .563, SD = .17) as opposed to the BI-TBI group mean (M = .458, SD = .144). A Mann-Whitney analysis was performed and also showed significant between-group differences on the ranks for *average gain: Z* = -2.81, *p* = .005.

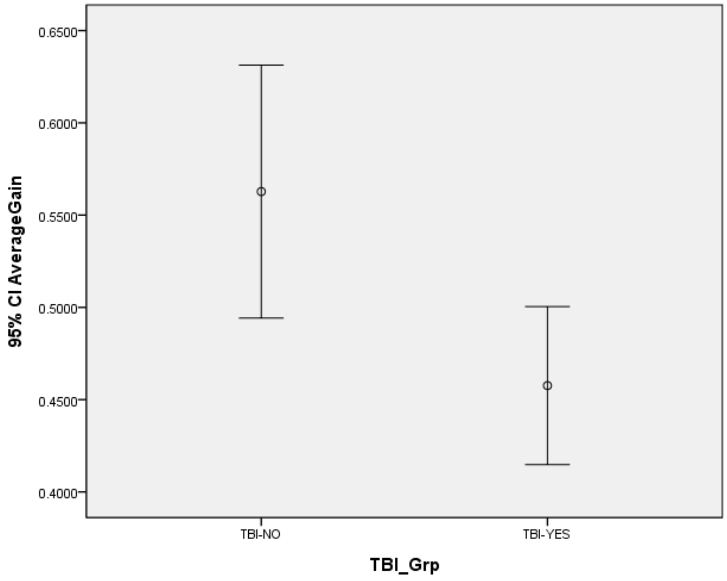

Figure 41. 95% Confidence Interval for the *average gain* variable on the Optokinetic Trapezoidal (60) subtest.

Visual Enhancement (.08, .16. .32, .64)

Description: In the Visual Enhancement subtest a visually enhanced vestibular occulo reflex (VVOR) was produced as the chair was rotated while diffuse lights were projected on the inside of the darkened NOTC surround. In this subtest, the chair rotated at .08 Hz, .16 Hz, .32 Hz. and .64 Hz. The *gain average*, *asymmetry*, and *phase* variables of this subtest were analyzed.

Visual Enhancement (.08) Results: A one-way ANOVA with an alpha level of .05 showed significance for *gain average: F* (1, 64) = 3.98, *p* = .05 (η^2 = .058, i.e., 5.8% of the variability in the outcome is attributable to between-group differences). The non-TBI group obtained a higher mean (*M* = .907, *SD* = .079) as opposed to the TBI group mean (*M* = .848, *SD* = .134).

A Mann-Whitney non-parametric analogue to the two-group ANOVA was performed, and commensurate with the findings for the ANOVA, there were significant between-group differences on the ranks for *gain average: Z* = -2.77, *p* = .006.

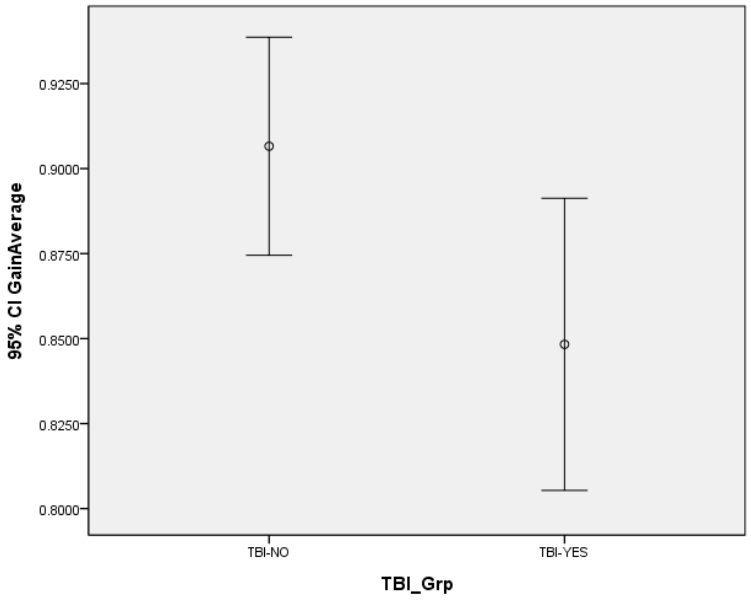

Figure 42. 95% Confidence Interval for the *gain average* and variable on the Visual Enhancement (.08) subtest.

Visual Enhancement (.16) Results: A one-way ANOVA did not show significance for any of the variables on this subtest. The largest effect size found for *gain average: F* (1, 61) = 2.25, *p* = .139 (η^2 = .036, i.e., 3.6% of the variability in the outcome is attributable to between-group differences). Though not significant, the non-TBI group obtained a higher mean (*M* = .910, *SD* = .089) as opposed to the TBI group mean (*M* = .869, *SD* = .120). A Mann-Whitney analysis

confirmed the ANOVA findings and showed no significant between-group differences on the ranks for any of the variables in this subtest.

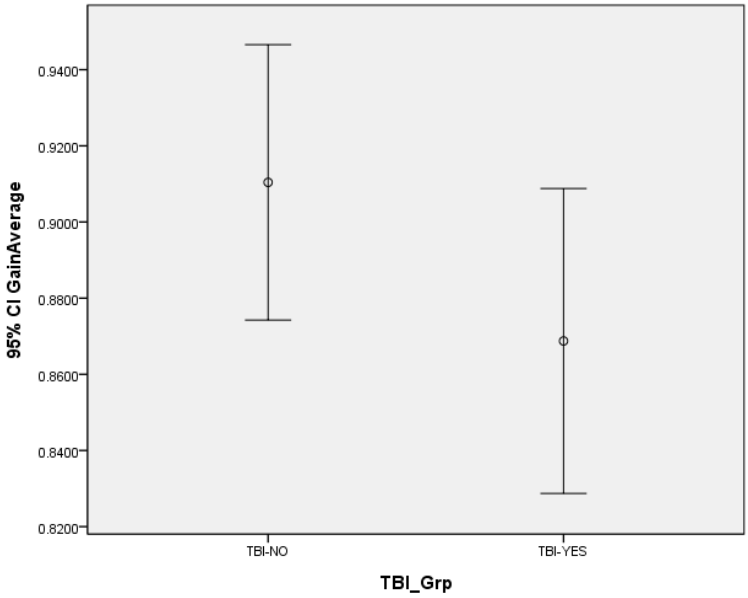

Figure 43. 95% Confidence Interval for the *gain average* and variable on the Visual Enhancement (.16) subtest.

Visual Enhancement (.32) Results: Statistical significance was not obtained for any of the variables on a one-way ANOVA (using alpha of .05). The largest effect size was found for *gain average: F* (1, 62) = 2.91, *p* = .093 (η^2 = .045, i.e., 4.5% of the variability in the outcome is attributable to between-group differences). Though not significant, the non-TBI group obtained a higher mean (*M* = .912, *SD* = .075) as opposed to the TBI group mean (*M* = .855, *SD* = .156). Also, given the large negative outlier for the *phase* variable, the ANOVA was re-analyzed without the outlier, and significance was still not obtained (*p* = .226).

A Mann-Whitney analysis showed significant between-group differences on the ranks for *phase: Z* = -2.95, *p* = .003 and for *gain average*, though not significant: *Z* = -1.85, *p* = .065.

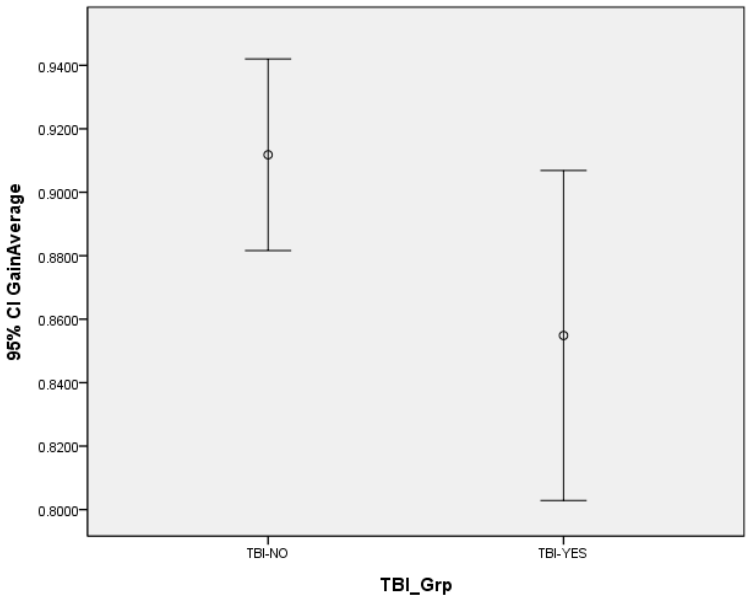

Figure 44. 95% Confidence Interval for the *gain average* and variable on the Visual Enhancement (.32) subtest.

Visual Enhancement (.64) Results: A one-way ANOVA using an alpha level of .05 showed significant between-group differences for the following variables:

Gain average: F (1, 66) = 5.98, *p* = .017 (η^2 = .083, i.e., 8.3% of the variability in the outcome is attributable to between-group differences). The non-TBI group obtained a higher mean (*M* = .833, *SD* = .096) as opposed to the TBI group mean (*M* = .856, *SD* = .132). *Phase: F* (1, 66) = 10-.35, *p* = .002 (η^2 = .136, i.e., 13.6% of the variability in the outcome is attributable to between-group differences). The non-TBI group obtained a higher mean (*M* = 4.96, *SD* = 1.85) as opposed to the TBI group mean (*M* = 1.55, *SD* = 5.19).

A Mann-Whitney test was performed, and commensurate with the results from the one-way ANOVA, when running the Mann-Whitney, there were significant between-group differences on the ranks for *gain average:* *Z* = -3.44, *p* = .001 and *phase*: *Z* = -4.51, *p* <.05.

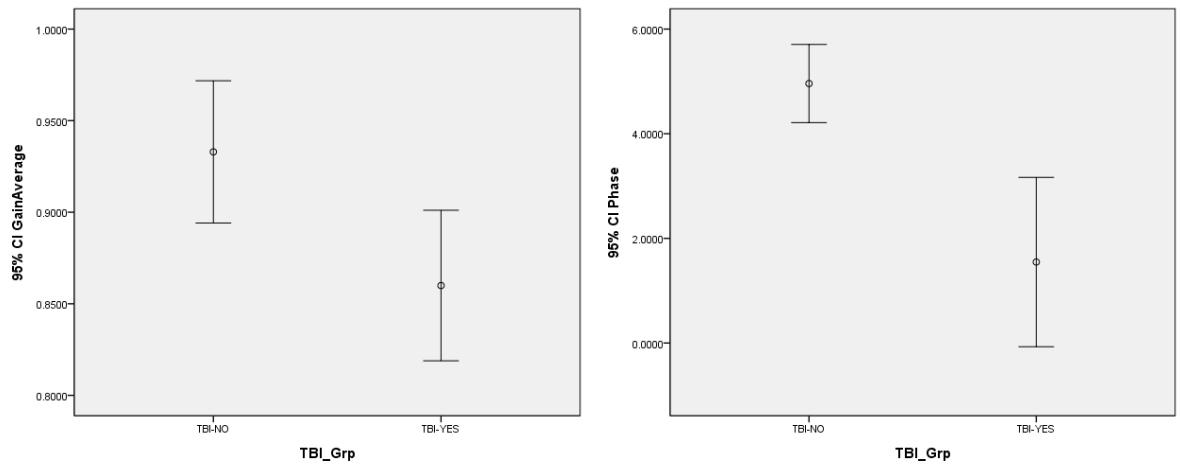

Figure 45. 95% Confidence Interval for the *gain average* and *phase* variables on the Visual Enhancement (.64) subtest.

Visual Suppression (.08, .16, .32, .64)

Description: In the Visual Suppression subtest, the chair was rotated while the participant was instructed to fixate on the laser dot projected on the inside of the darkened NOTC surround. The results of the visual suppression tests evaluate the ability of the volunteer participant to suppress the reflex responsible for nystagmus. The chair was rotated at .08 Hz, .16 Hz, .32 Hz. and .64 Hz. Participants were instructed to keep their eyes fixed on the light that they saw on the wall while the chair rotated, that is suppress his/her nystagmus during the visual suppression test). The *gain average*, *asymmetry*, and *phase* variables of this subtest were analyzed.

Visual Suppression (.08) Results: A one-way ANOVA showed between-group significant differences for the *gain average* variable*: F* (1, 65) = 4.50, *p* = .038 (η^2 = .065, i.e., 6.5% of the variability in the outcome is attributable to between-group differences). The TBI group obtained a higher mean (*M* = .085, *SD* = .051) as opposed to the non-TBI group mean (*M* = .062, *SD* = .027).

A Mann-Whitney analysis was performed and consistent with the findings for the ANOVA, there were significant between-group differences on the ranks for *gain average***:** *Z* = -1.98, *p* = .048 (and *Z* = -1.79, *p* = .074 for *asymmetry*).

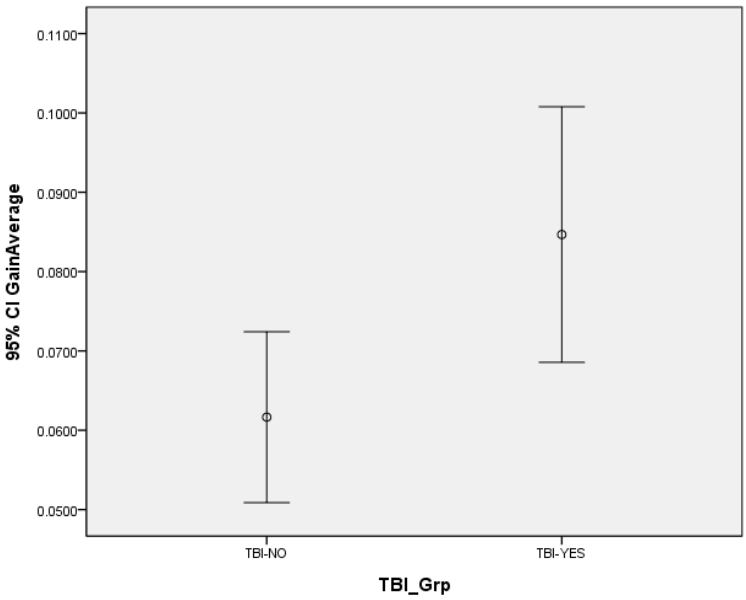

Figure 46. 95% Confidence Interval for the *gain average* and variable on the Visual Suppression (.08) subtest.

Visual Suppression (.16) Results: When conducting the one way ANOVA (using alpha of .05) significance was found for *gain average: F* (1, 63) = 6.34, *p* = .014 (η^2 = .091, i.e., 9.1% of the variability in the outcome is attributable to between-group differences). The TBI group obtained a higher mean (*M* = .087, *SD* = .054) as opposed to the non-TBI group mean (*M* = .059, *SD* = .026). A Mann-Whitney analysis was performed and also revealed significant between-group differences on the ranks for *gain average***:** *Z* = -2.68, *p* = .007, but opposed to ANOVA significance was found for *asymmetry*: *Z* = -2.65, *p* = .008.

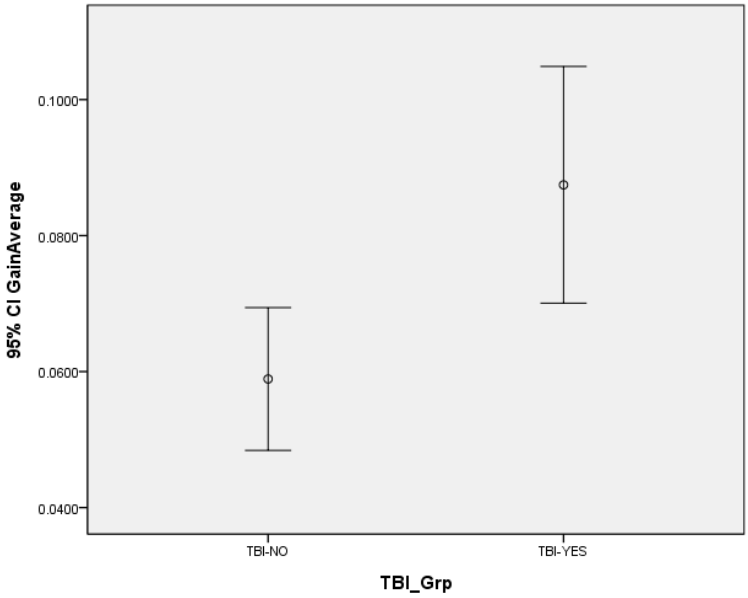

Figure 47. 95% Confidence Interval for the *gain average* and variable on the Visual Suppression (.16) subtest.

Visual Suppression (.32) Results: ANOVA (using alpha of .05) found significance for *gain average: F* (1, 65) = 4.73, *p* = .033 (η^2 = .068, i.e., 6.8% of the variability in the outcome is attributable to between-group differences). The TBI group obtained a higher mean (*M* = .112, *SD* = .065) as opposed to the non-TBI group mean (*M* = .082, *SD* = .038). The Mann-Whitney test was performed, and as opposed to the findings for the ANOVA, *gain average* was not significant: *Z* = -1.90, *p* = .057, but significance was found for *asymmetry*: *Z* = -2.39 *p* = .017

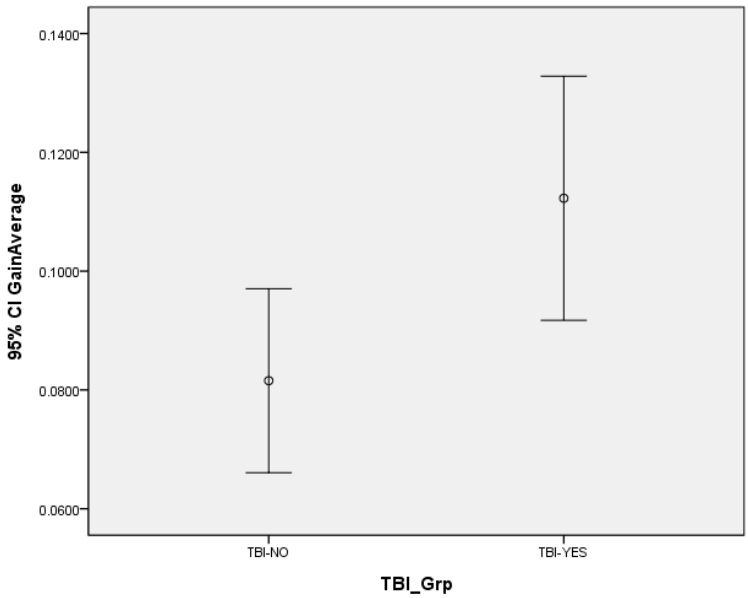

Figure 48. 95% Confidence Interval for the *gain average* and variable on the Visual Suppression (.32) subtest.

Visual Suppression (.64) Results: One way ANOVA (using alpha of .05) did not show significance for any of the variables; however, the largest effect size was found for *gain average:* F (1, 73) = 3.72, p = .058 (η^2 = .048, i.e., 4.8% of the variability in the outcome is attributable to between-group differences). The TBI group obtained a higher mean (M = .157, SD = .085) as opposed to the non-TBI group mean (M = .120, SD = .061). Deletion of the two large negative outliers from *phase* (both are from the TBI group), also resulted in no between-group significant differences (p = .149).

A Mann-Whitney analysis was performed, and as opposed to the findings for the ANOVA, *gain average* is significant: Z = -2.20, p = .028, as well as *phase:* Z = -2.05, p = .041, with a higher mean rank for non-TBI group.

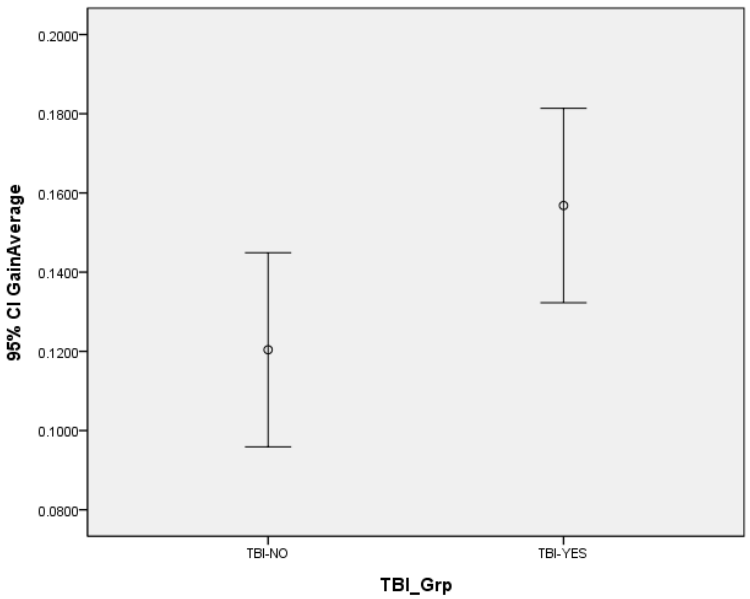

Figure 49. 95% Confidence Interval for the *gain average* and variable on the Visual Suppression (.64) subtest.

Subjective Visual Vertical

Description: The Subjective Visual Vertical subtest was a test of perceptual vertical. In this test, a non-vertical line was projected on the inside of the darkened NOTC surround. Participants were directed to use the control buttons at the top of the handholds to adjust the line to vertical. Holding the buttons down, the line rotated clockwise or counterclockwise at 1 degree / second in 0.1 degree increments. If the participant began to adjust the line in the wrong direction, he/she was directed to push the button on the other handhold. Once the line became near vertical, the participant was instructed that he/she may move the line back and forth using both buttons until

he/she was satisfied that the line was vertical. He or she then signaled the operator and testing proceeded to the next test. Each test must was repeated five times (six iterations) for statistical validity. There was no rotary chair movement in this subtest. The *mean* value in degrees of line adjustment was the variable used for statistical analysis in this subtest.

Mean Results: One way ANOVA (using alpha of .05) did not reveal significance for the *mean* variable: F (1, 74) = .165, p = .686 (η^2 = .001, i.e., .2% of the variability in the outcome is attributable to between-group differences). Though not significant, the non-TBI group obtained a higher (in absolute value) mean (M = -.380, SD = 2.36) as opposed to the TBI group mean (M=.131, SD = 2.62). A Mann-Whitney test confirmed a lack of significance for this variable (Z=.099, p = .922).

Subjective Visual Horizontal

Description: The Subjective Visual Horizontal subtest was a test of perceptual horizontal. In this test, a non-horizontal line was projected on the inside of the darkened NOTC surround. Participants were directed to use the control buttons at the top of the handholds to adjust the line to horizontal. Holding the buttons down, the line rotated clockwise or counterclockwise at 1 degree / second in 0.1 degree increments. If the participant began to adjust the line in the wrong direction, he/she was directed to push the button on the other handhold. Once the line became near horizontal, the participant was instructed that he/she may move the line back and forth using both buttons until he/she was satisfied that the line was horizontal. He or she then signaled the operator and testing proceeded to the next test. Each test must was repeated five times (six iterations) for statistical validity. There was no rotary chair movement in this subtest. The *mean* value in degrees of line adjustment was the variable used for statistical analysis in this subtest.

Mean Results: One way ANOVA analysis did not show significance for the *mean* variable: F (1, 69) = .471, p = .495 (η^2 = .007, i.e., .7% of the variability in the outcome is attributable to between-group differences). Though not significant, the TBI group obtained a higher (in absolute value) mean (M = -.693, SD = 1.96) as opposed to the non-TBI group mean (M = -.368, SD = 1.86). A Mann-Whitney analysis was consistent with ANOVA: significance was not obtained for *mean* (Z = -.119, p = .905).

KEY RESEARCH ACCOMPLISHMENTS

- There are differences between the auditory and vestibular function of Soldiers without history of BI-TBI and those with a history of BI-TBI.
- The differences in vestibular function are specific to particular rotary chair subtests.

- The research test protocol proved to be useful in a clinical setting.
- The test protocol could be tolerated by Soldiers with TBI symptoms and did not appear to exacerbate symptoms.
- The Neuro-Kinetics I-Portal NOTC System instrumentation proved to be reliable and safe.
- The test systems built-in scoring metrics were adequate to reveal differences between groups.

REPORTABLE OUTCOMES

No manuscripts, abstracts, or presentations have resulted from this research at this time. However, as a result of this work, normative vestibular function parameters for healthy military members have been established for the Neuro-Kinetics I-Portal Neuro-Otologic Test Center (NOTC) System.

Additionally, this work has supported development of research protocols for the Medical Research and Materiel Command's (MRMC) Military Operational Medicine Research Program (MOMRP) task area P: Return-to-Duty Standards and Strategies after Neurosensory Injury. Specifically, the work conducted under this grant was leveraged to facilitate the MOMRP-funded project titled "Development of auditory, visual, and vestibular test batteries to establish objective return-to-duty standards for concussive mTBI patients".

CONCLUSION

This study found statistically significant and clinically important differences between service members who have suffered the effects of a blast-induced traumatic brain injury. Statistically significant differences in hearing ability were demonstrated, with the BI-TBI group showing more hearing loss as a group. It was also observed that there are specific subtests of the vestibular test battery that are more sensitive to the differences than others. A summary of significant findings is included in Appendix D.

Analysis of several oculomotor subtests revealed statistically different outcomes between the non-TBI and BI-TBI groups. Maintaining clear vision during movement is dependent upon a combination of inputs from the vestibular and ocular systems passing information through the brain. Smooth pursuit movements allow clear vision during a slow movement and the vestibulo-occular reflex (VOR) provides clear vision during a fast movement. The smooth pursuit system tracks a single moving object and the optokinetic system tracts a moving field of objects. Saccadic eye movements rapidly reposition eyes to maintain a target.

Smooth pursuit testing, the ability to follow a slow moving target, was found to be different between the BI-TBI group and the non-TBI group. The BI-TBI groups showed a higher rate of saccadic eye movements to maintain the speed of tracking a target and at some speeds were less effective at maintaining the target. An ineffective pursuit system could result in functional limitations such as limited ability to drive and play sports successfully (Scheiman, 2002) because of difficulty following a target visually.

There were also differences in the saccadic testing, specifically, differences in accuracy, overall accuracy, latency, velocity, and undershoots in the BI-TBI group compared to the non-TBI group. The saccadic eye movements of the BI-TBI population took a longer time to start the moving, moved slower, and were less accurate than those of the non-TBI population. Important functions of saccadic eye movements include facilitating the ability to search visually, copy design, and read. These eye movements also allow one to scan environments and faces efficiently. Inefficiencies with saccadic eye movements could manifest as functional limitations or subjective complaints associated with reading, detecting spaces between words, and copying information down (Leigh, 2006).

Optokinetic (OKN) testing analysis demonstrated that the BI-TBI group was not able to produce reflexive eye movements that moved at the speed of a visual target as well as the non-TBI group. The OKN system, when intact, helps stabilize the image of a moving field of targets. Clinically a person may complain that they are unable to tolerate the perception of moving trees or telephone poles outside of a moving car (Jacobson, 2008).

Visual enhancement testing evaluates both the VOR and the OKN systems. Again the BI-TBI group disclosed that the speed of eye movements were slower than that of the targets when compared to the non-TBI group. Maintaining clear vision when in movement is expected to be less effective such as when riding in a vehicle and causing the person to feel dizzy,

Visual suppression gain proved to be higher for the BI-TBI group, meaning that this group was not able to suppress eye movements as well as the non-TBI group when the body was in movement. This could affect one's ability to view a target as stationary as their head was in motion such as during walking or running.

All significant findings disclosed that it is more challenging for the BI-TBI population to maintain clear vision and avoid dizziness than that of the non-TBI population. A soldier's ability to successfully read a map, travel in a vehicle, maintain a target, or accurately shoot a weapon may be affected by these deficits. Compromised ability to maintain clear vision when the body was in motion when walking or running would also be expected.

Importantly, it was also discovered that identification of the differences can be accomplished with currently available clinical equipment. The cost of the equipment used for this study may be prohibitive for some clinics, but further examination of the subtests that were sensitive to the

identified differences may lead to the realization that the evaluation can be conducted on more affordable equipment.

Multiple manuscripts should result from this work. There are not currently established clinical normative databases for many of the vestibular testing subtests, and data from this study could form the basis for such a database. It was also observed that a certain subgroup of our test population performed in an unexpected manner that we suspect is due to experience with military training. This effect will be examined more thoroughly.

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Appendix A – Dizziness Handicap Inventory

Dizziness Handicap Inventory

Name: _____ DOB: _____ Date: _____

Instructions: The purpose of this scale is to identify difficulties that you may be experiencing because of your dizziness or unsteadiness. Please answer "yes", "no" or "sometimes" to each question.
Answer each question as it applies to your dizziness or unsteadiness only.

ITEM	QUESTION		Y	N	S
1	Does looking up increase your problem?	P			
2	Because of your problem, do you feel frustrated?	E			
3	Because of your problem, do you restrict your travel for business or recreation?	F			
4	Does walking down the aisle of a supermarket increase your problem?	P			
5	Because of your problem, do you have difficulty getting into or out of bed?	F			
6	Does your problem significantly restrict your participation in social activities such as going out to dinner, the movies, dancing or to parties?	F			
7	Because of your problem, do you have difficulty reading?	F			
8	Does performing more ambitious activities such as sports or dancing or household chores such as sweeping or putting dishes away increase your problem?	P			
9	Because of your problem, are your afraid to leave your home without having someone accompany you?	E			
10	Because of your problem, are you embarrassed in front of others?	E			
11	Do quick movements of your head increase your problem?	P			
12	Because of your problem, do you avoid heights?	F			
13	Does turning over in bed increase your problem?	P			
14	Because of your problem, is it difficult for you to do strenuous housework or yard work?	F			
15	Because of your problem, are you afraid people may think you are intoxicated?	E			
16	Because of your problem, is it difficult for you to walk by yourself?	F			
17	Does walking down a sidewalk increase your problem?	P			
18	Because of your problem, is it difficult for you to concentrate?	E			
19	Because of your problem, is it difficult for you to walk around the house in the dark?	F			
20	Because of your problem, are you afraid to stay at home alone?	E			
21	Because of your problem, do you feel handicapped?	E			
22	Has your problem placed stress on your relationship with members of your family or friends?	E			
23	Because of your problem, are you depressed?	E			
24	Does your problem interfere with your job or household responsibilities?	F			
25	Does bending over increase your problem?	P			
			X 4	X 0	X 2
		=			
		TOTAL			

P _____ E _____ F _____

□ 100-70= severe perception of having a handicap, □ 69-40= moderate perception of handicap, □ 39-0= low perception of handicap

Appendix B

3 Question DVBIC TBI Screening Tool

Instruction Sheet

Purpose and Use of the DVBIC 3 Question TBI Screen

The purpose of this screen is to identify service members who may need further evaluation for mild traumatic brain injury (TBI).

Tool Development

The 3 Question DVBIC TBI Screening Tool, also called The Brief Traumatic Brain Injury Screen (BTBIS), was validated in a small, initial study conducted with active duty service members who served in Iraq/Afghanistan between January 2004 and January 2005.

Schwab, K. A., Baker, G., Ivins, B., Sluss-Tiller, M., Lux, W., & Warden, D. (2006). The Brief Traumatic Brain Injury Screen (BTBIS): Investigating the validity of a self-report instrument for detecting traumatic brain injury (TBI) in troops returning from deployment in Afghanistan and Iraq. *Neurology, 66*(5)(Supp. 2), A235.

Who to Screen

Screen should be used with service members who were injured during combat operations, training missions or other activities.

Screening Instructions

Question 1: A checked [√] response to any item A through F verifies injury.

Question 2: A checked [√] response to A-E meets criteria for a positive (+) screen. Further interview is indicated. A positive response to F or G does not indicate a positive screen, but should be further evaluated in a clinical interview.

Question 3: Endorsement of any item A-H verifies current symptoms which may be related to a mild TBI if the screening and interview process determines a mild TBI occurred.

Significance of Positive Screen

A service member who endorses an injury [Question 1] as well as an alteration of consciousness [Question 2 A-E], should be further evaluated via clinical interview because he/she is more highly suspect for having sustained an mild TBI or concussion. The MTBI screen alone does not provide diagnosis of mild TBI. A clinical interview is required.

For more information contact: Telephone: 1-800-870-9244 Email: info@DVBIC.org Web: www.DVBIC.org

3 Question DVBIC TBI Screening Tool

1. Did you have any injury(ies) during your deployment from any of the following? (Check all that apply):

A. □ Fragment

B. □ Bullet

C. □ Vehicular (any type of vehicle, including airplane)

D. □ Fall

E. □ Blast (Improvised Explosive Device, RPG, Land mine, Grenade, etc.)

F. □ Other specify: _____

2. Did any injury received while you were deployed result in any of the following? (Check all that apply):

A. □ Being dazed, confused or "seeing stars"

B. □ Not remembering the injury

C. □ Losing consciousness (knocked out) for less than a minute

D. □ Losing consciousness for 1-20 minutes

E. □ Losing consciousness for longer than 20 minutes

F. □ Having any symptoms of concussion afterward (such as headache, dizziness, irritability, etc.)

G. □ Head Injury

H. □ None of the above

3. Are you currently experiencing any of the following problems that you think might be related to a possible head injury or concussion? (Check all that apply):

A. □ Headaches E. □ Ringing in the ears

B. □ Dizziness F. □ Irritability

C. □ Memory problems G. □ Sleep problems

D. □ Balance problems H. □ Other specify:_____

NOTE: Confirm F and G through clinical interview

NOTE: Endorsement of A-E meets criteria for positive TBI Screen

For more information contact: Telephone: 1-800-870-9244 Email: info@DVBIC.org Web: www.DVBIC.org.

Appendix C

Blast Exposure Survey Blast Exposure Survey

1. What type of blast were you exposed to? *Place a check mark next to the appropriate selection(s)*

☐ RPG

☐ Ambush involving small arms fire (please describe)

☐ Shells or rounds dropped during a call for fire (please describe)

☐ IED (please describe)

☐ Car bomb (please describe)

2. When were you exposed to the blast described above? *Place a check mark next to the appropriate selection(s)*

☐	1 month ago	☐	1-2 years ago
☐	2 months ago	☐	2-3 years ago
☐	3 months ago	☐	3-4 years ago
☐	3-6 months ago	☐	4-5 years ago
☐	7-12 months ago	☐	5 years ago
☐	1 year	☐	Over 5 years ago

3. Approximately how far were you from the blast? *Place a check mark next to the appropriate selection(s)*

☐	25 meters	☐	½ mile
☐	50 meters	☐	1 mile
☐	100 meters	☐	Other

Appendix D

Significant Rotary Chair Differences Between BI-TBI and non-TBI groups

Subtest	Variable	Higher Mean Group
Smooth Harmonic Acceleration (.32)	Asymmetry	Non-TBI
Smooth Harmonic Acceleration (.64)	Phase	Non-TBI
Smooth Harmonic Acceleration (1.75)	Gain average Phase	Non-TBI
Saccades Horizontal	Left eye accuracy Right eye accuracy Undershoot Latency Velocity	Non-TBI Non-TBI BI-TBI BI-TBI BI-TBI
Saccades Vertical	Undershoot Overshoot Latency Velocity	BI-TBI Non-TBI BI-TBI Non-TBI
Smooth Pursuit Horizontal (0.1)	Percent saccade Asymmetry	BI-TBI Non-TBI
Smooth Pursuit Vertical (0.1)	Downward gain Percent saccade	Non-TBI BI-TBI
Smooth Pursuit Vertical (0.71)	Gain asymmetry	BI-TBI
Gaze Horizontal (left)	Horizontal fixation lights off Vertical fixation lights off	BI-TBI BI-TBI
Gaze Horizontal (right)	Horizontal fixation lights on Vertical fixation lights on	BI-TBI BI-TBI
Optokinetic Trapezoidal (20)	Average gain	Non-TBI
Optokinetic Trapezoidal (40)	Average gain	Non-TBI
Optokinetic Trapezoidal (60)	Average gain	Non-TBI
Visual Enhancement (0.8)	Gain average	Non-TBI
Visual Enhancement (0.64)	Gain average Phase	Non-TBI Non-TBI
Visual Suppression (0.8)	Gain average	BI-TBI
Visual Suppression (0.16)	Gain average	BI-TBI
Visual Suppression (0.32)	Gain average	BI-TBI